Energy Reports 12 (2024) 4475–4488

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Review article

Empowering communities beyond wires: Renewable energy microgrids and the impacts on energy poverty and socio-economic outcomes

Phemelo Tamasiga [a,b,*], Helen Onyeaka [c,**], Moutaz Altaghlibi [d], Malebogo Bakwena [e], El houssin Ouassou [f]

[a] German Institute of Development and Sustainability, Bonn, Germany
[b] CRETEGI, Centre of Research in Energy, Trade and Green Industrialisation, Gaborone, Botswana
[c] School of Chemical Engineering, University of Birmingham, Birmingham, UK
[d] ABN AMRO Bank N.V, the Netherlands
[e] Department of Economics, University of Botswana, Gaborone, Botswana
[f] Laboratory of Applied Economics (LAE), Mohammed V University in Rabat, Rabat, Morocco

ARTICLE INFO

Keywords:
microgrids
energy poverty
renewable energy
sustainable development goals (SDGs)

ABSTRACT

This systematic review investigates the impact of renewable energy microgrids on alleviating energy poverty and enhancing socio-economic outcomes in underserved communities. The study addresses the critical challenge of energy access, examining how small-scale renewable energy systems integrated with microgrids can serve as a sustainable solution. Using a structured methodology, the review synthesizes evidence from various studies to provide insights into the multifaceted implications of microgrid adoption. The key findings indicate that renewable energy microgrids significantly contribute to socio-economic development by improving livelihoods, economic growth, and enhancing food security, health, and education. The review also highlights economic assessments affirming the cost-effectiveness of these systems and the environmental benefits they offer, such as reduced emissions of greenhouse gases. However, the study also identifies challenges, including high initial capital costs, operational complexities, and regulatory barriers. The conclusions drawn from this review underscore the necessity for innovative financing solutions, supportive policy frameworks, and community engagement strategies to overcome these challenges. The alignment of microgrid solutions with the Sustainable Development Goals (SDGs) further demonstrates their potential to drive broader sustainable development objectives.

1. Introduction

The energy needs of industrial production in various sectors and communities face a common challenge: the significant emission of greenhouse gases (GHGs) from power plants. This issue is compounded by the high expansion costs associated with traditional systems and the energy losses in transmission and distribution networks (Deng and Lv, 2020; Lund et al., 2015; Nwaigwe et al., 2019). Furthermore, Deng and Lv (2020) highlighted that power system planning must evolve to handle increasing variable renewable energy sources, suggesting that

List of Abbreviations;: ADNs, Active Distribution Networks; CO2-eq/yr, Carbon Dioxide Equivalent per Year; DCLs, Domestic Controllable Loads; FEW, Food, Energy, and Water; GHG, Greenhouse Gas; HRES, Hybrid Renewable Energy Systems; HREM, Hybrid Renewable Energy Microgrid; KWh, Kilowatt Hour; LCOE, Levelized Cost of Energy; MDSTool, Microgrid Decision Support Tool; PAYG, Pay-As-You-Go; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; PV, Photovoltaic; RE, Renewable Energy; SDGs, Sustainable Development Goals; SDGs 1, No Poverty; SDGs 2, Zero Hunger; SDGs 3, Good Health and Well-Being; SDGs 4, Quality Education; SDGs 5, Gender Equality; SDGs 6, Clean Water and Sanitation; SDGs 7, Affordable and Clean Energy; SDGs 8, Decent Work and Economic Growth; SDGs 9, Industry, Innovation, and Infrastructure; SDGs 10, Reduced Inequalities; SDGs 11, Sustainable Cities and Communities; SDGs 12, Responsible Consumption and Production; SDGs 13, Climate Action; SDGs 14, Life Below Water; SDGs 15, Life on Land; SDGs 16, Peace, Justice, and Strong Institutions; SDGs 17, Partnerships for the Goals; SGs, Smart Grids; SWROD, Sea Water Reverse Osmosis Desalination; TWh/yr, Terawatt Hours per Year; VAT, Value Added Tax; WoS, Web of Science.

* Corresponding author at: German Institute of Development and Sustainability, Bonn, Germany.
** Corresponding author.
E-mail addresses: phemelo.tamasiga@idos-research.de (P. Tamasiga), H.Onyeaka@bham.ac.uk (H. Onyeaka).

https://doi.org/10.1016/j.egyr.2024.10.026
Received 1 April 2024; Received in revised form 28 August 2024; Accepted 15 October 2024
Available online 22 October 2024

optimization models can address current inefficiencies. Lund et al. (2015) further accentuate the necessity for energy system flexibility measures that accommodate high levels of variable renewable electricity, while Nwaigwe et al. (2019) focus on the integration challenges of photovoltaic (PV) systems into electricity grids, identifying power losses as a critical barrier. These factors underscore the urgent need to reform the current energy landscape in alignment with Sustainable Development Goal 7 (SDG7), which aims to ensure universal access to affordable and stable electricity while addressing environmental and economic challenges (Jaccard et al., 1997).

As an innovative response to these challenges, the integration of small-scale renewable energy microgrids emerges as a compelling solution, particularly in the context of SDG7, which emphasizes "Affordable and Clean Energy" (Madurai Elavarasan et al., 2021; Mendes et al., 2011; Warneryd et al., 2020). According to Madurai Elavarasan et al. (2021), microgrids hold significant potential in advancing energy sustainability and resilience in a post-COVID-19 world. Mendes et al. (2011) provide a comprehensive survey of available tools for the planning and analysis of Integrated Community Energy Systems, indicating that microgrids can mitigate global warming impacts while promoting energy access and sustainability. However, Warneryd et al. (2020) elucidate the institutional roles vital for microgrid development, which include legislative incentives and robust governance structures. This evolving technology also poses its complexities, including high capital costs, concerns about operational stability, uncertainties, and intricate management and maintenance demands (Ali Dashtaki et al., 2023; Elkadeem et al., 2021; Montoya-Duque et al., 2022).

The transition from traditional energy resources to distributed generation facilitated by microgrids results in cleaner energy and significantly reduced transmission and distribution losses (Hirsch et al., 2018; Saeed et al., 2021). Moreover, Aga et al. (2023) emphasize that hybrid renewable energy-based off-grid technology can provide sustainable electrification solutions for rural communities. Hirsch et al. (2018) offer a detailed review of microgrid technologies, key drivers, and outstanding issues, acknowledging that the shift towards distributed generation alleviates energy losses and fosters technological advancement and sustainability. A related study by Saeed et al. (2021) discusses the challenges and perspectives in microgrid deployment, underscoring microgrids' role in offering relief from high fuel prices and providing a viable alternative as fossil fuel reserves wane. Chen et al. (2021) argues for the versatility of microgrids in modern power systems, emphasizing their ability to operate connected to the grid and in isolation, which is crucial for their integration into modern power structures. The versatility of microgrids, which can operate both connected to the grid- and in isolation, highlights their importance in modern power systems (Chen et al., 2021; D et al., 2023; Rizvi and Abu-Siada, 2023; Vaahedi et al., 2020). Successful integration requires alignment of institutional and governance structures to support microgrid adoption. Legislative incentives and strong institutions create an enabling environment for the transition to clean energy and encourage the adoption of microgrids. This strategic support ensures a smooth transformation in the state's energy system, allowing microgrids to enter without threatening the existing utility-dominated electricity system (Ajaz and Bernell, 2021).

The adoption and scalability of microgrids also require careful consideration of institutional and governance structures. Ajaz and Bernell (2021) illustrate how legislative incentives and strong institutions create an enabling environment for the transition to clean energy, ensuring microgrids do not disrupt the existing utility-dominated electricity system. In this context, aligning institutional frameworks to support microgrid adoption is essential, facilitating a smooth transformation in the state's energy infrastructure.

Despite the significant benefits of microgrids over conventional grids, such as enhanced reliability, environmental sustainability, and cost-effectiveness, inherent challenges persist (Shahzad et al., 2023). Shahzad et al. (2023) highlight these challenges, which range from high initial capital investments to technical complexities and regulatory nuances. Akinyele et al. (2018) utilize the STEEP model to analyze these challenges in remote communities, pointing out the socio-technical barriers that must be addressed. Chatterjee et al. (2019) review the research insights necessary for developing remote, off-grid microgrids in developing countries, identifying strategies to overcome these barriers. Monagas and Corral (2022) explore the socio-technical challenges in exporting Western renewable energy microgrids to African islands, emphasizing the need for context-specific solutions.

This systematic review aims to provide a comprehensive understanding of microgrid development by uncovering barriers and offering insights into the strategies and technologies necessary for successful navigation. It seeks to contribute to strategic policy decision-making and resource allocation by highlighting the potential of microgrids in the transition towards green energy (Naji Alhasnawi et al., 2020; Salkuti, 2022). Naji Alhasnawi et al. (2020) propose a robust energy management strategy for hybrid microgrid systems, emphasizing green energy integration. Similarly, Salkuti (2022) discusses advanced green energy technologies for a sustainable and resilient future grid, underscoring the importance of microgrids in achieving sustainable development goals.

With this objective in mind, the following research questions are formulated: (1) What socio-economic outcomes can be attributed to implementing small-scale renewable energy microgrids, and how do these outcomes align with the Sustainable Development Goals (SDGs)? (2) What are the potential barriers and challenges associated with the adoption and scalability of small-scale renewable energy microgrids, and how can policy frameworks, technological innovations, and social and environmental solutions be tailored to overcome these obstacles?

This systematic review makes several significant contributions. First, it delves deep into the socio-economic outcomes and examines their alignment with the SDGs. Second, it provides insights into digital technologies' role in enhancing agri-food supply chain resilience. Third, it demonstrates how stakeholders can effectively utilize small-scale renewable energy microgrids by integrating policy measures, technological progress, social engagement, and environmental principles. This approach promotes sustainable development, improves community resilience, and improves livelihoods.

The paper is structured as follows: Section 1, Introduction, provides a background on the current energy landscape challenges and the potential of renewable energy microgrids. Section 2, Methodology, outlines the systematic review approach, including the literature search strategy, inclusion and exclusion criteria, and data extraction processes. Section 3, Results and Analysis, presents the findings of the review, categorized into socio-economic outcomes, energy poverty impacts, and their alignment with Sustainable Development Goals. Section 4, Discussion, discusses the socio-economic and environmental implications and explores potential barriers and solutions for microgrid adoption. Finally, Section 5, Conclusion and Policy Recommendations, summarizes the study's key insights and offers policy recommendations and research directions for enhancing the deployment and impact of microgrids.

2. Methodology

This systematic literature review follows a structured methodology to assess the impact of small-scale renewable energy microgrids on energy poverty and socio-economic outcomes. The review aims to synthesize existing literature and provide insights into the multifaceted implications of microgrid adoption. A systematic literature review is a research approach that investigates, selects, and evaluates all pertinent empirical information on a specific subject (Bearman et al., 2012; Krnic Martinic et al., 2019; Pollock & Berge, 2018).

The systematic literature reviews adhered to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) protocol, which outlines criteria for identifying, screening, and including relevant records. PRISMA is an evidence-based framework that ensures the comprehensiveness, transparency, and scientific integrity of systematic reviews and meta-analyses (Moher et al., 2015). The PRISMA flow diagram guided the search procedure, and the steps were organized under data collection and analysis, as detailed in the subsequent sections (see Fig. 1).

2.1. Literature search strategy

We conducted systematic literature using Scopus and Web of Science databases. The data was first retrieved on 08.12.2023, and an update was made on 17.01.2024. The search utilized a combination of keywords and phrases, such as "microgrids," "renewable energy," "energy poverty," and "socio-economic outcomes,". The search was further refined by applying inclusion and exclusion criteria to ensure the relevance and quality of the selected studies (see Table 1).

For this systematic review, we used a two-phase screening approach. In the initial phase, titles, keywords, and abstracts were evaluated to determine compatibility with the eligibility criteria. In the second phase, full-text articles deemed potentially relevant were carefully examined, and irrelevant articles were excluded from the search results.

2.2. Inclusion and exclusion criteria

Table 1 outlines the eligibility criteria for the studies included in the systematic review. It describes the logical search query formulated for the Scopus and Web of Science (WoS) databases, as well as the inclusion and exclusion criteria applied to ensure the relevance and quality of the selected studies.

For the Scopus database, the search query includes a comprehensive set of keywords and logical operators targeting studies related to Africa or Sub-Saharan Africa. It focuses on various aspects of energy, including electricity, electrification, access, connection, microgrids, grids, off-grid electricity, solar, photovoltaic, wind, hydro, renewables, and low-carbon energy. The query also covers energy issues such as energy poverty, consumption, access, electricity access, supply, and demand, alongside socio-economic factors like income, expenditure, revenue, profit, production, economy, capital, assets, employment, jobs, labor, education, school, inequality, poverty, and welfare. The WoS search query follows a similar structure, ensuring that a wide range of relevant studies are captured in both databases.

The inclusion criteria specify that only documents written in English and containing the specified keywords are considered for the review. This ensures consistency and comprehensibility in the review process while maintaining relevance to the topic of renewable energy microgrids and their impacts on energy poverty and socio-economic outcomes. Conversely, the exclusion criteria rule out documents not written in English and those not containing the specified keywords, ensuring that only pertinent studies are included in the analysis.

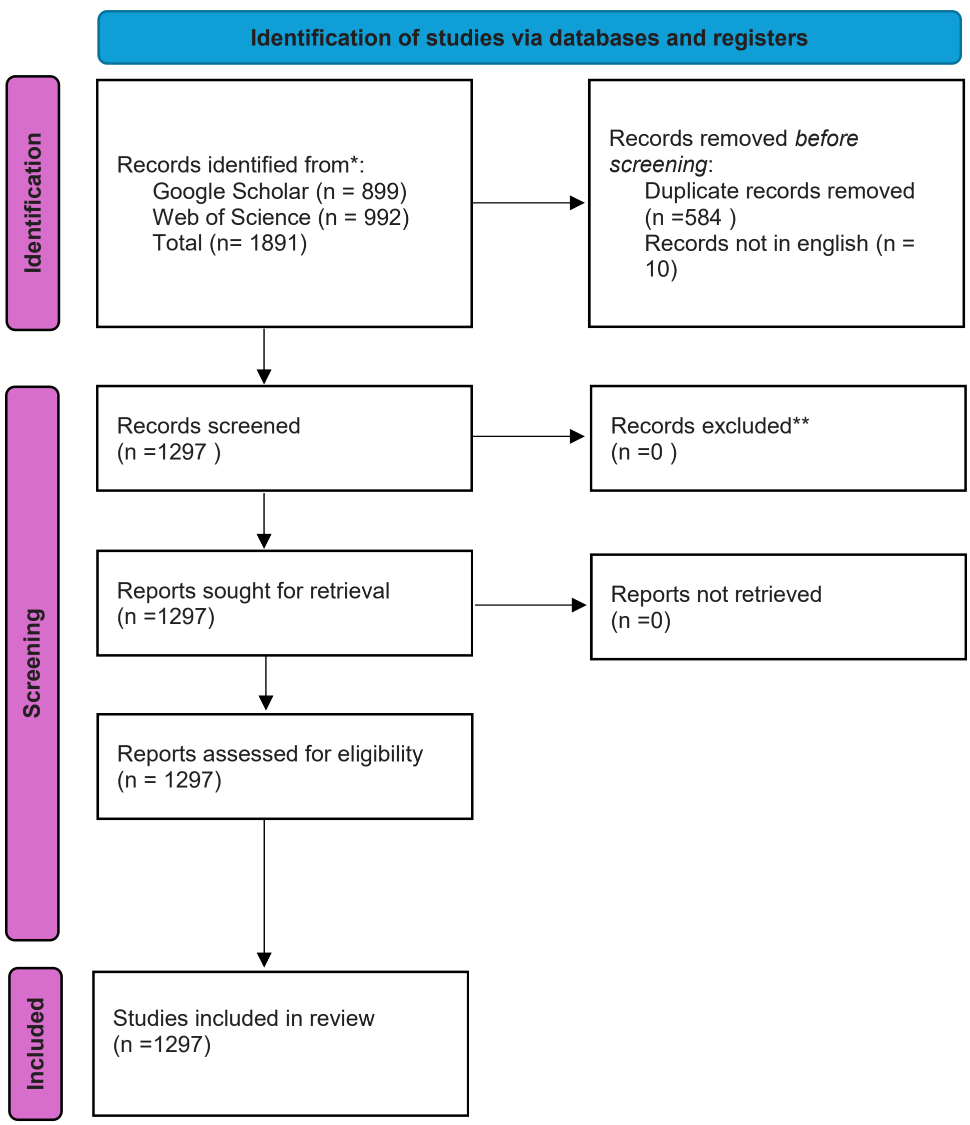

Fig. 1. PRISMA flow chart of the systematic review.

Table 1
Inclusion and Exclusion Criteria.

	Criteria
Logical Statement Scopus	TITLE-ABS-KEY ((Africa* OR "Sub-Saharan Africa") AND (electricity OR electrification) AND (access OR connect* OR "microgrid" OR "grid" OR "off-grid electricity" OR solar* OR photovoltaic OR wind OR hydro OR renewable* OR "low carbon energy") AND ("energy poverty" OR "energy consumption" OR "energy access" OR "electricity access" OR "energy supply" OR "energy demand") AND (income* OR expenditure OR revenue OR profit OR produc* OR econom* OR capital OR assets OR employ* OR job* OR labor OR labour OR work* OR educat* OR school* OR inequality OR poor OR rich OR low-income OR high-income OR poverty OR welfare))
Logical Statement WoS	TS= ((africa* OR "Sub-Saharan Africa") AND (electricity OR electrification) AND (access OR connect* OR "micro grid" OR "grid" OR "off-grid electricity" OR solar* OR photovoltaic OR wind OR hydro OR renewable* OR "low carbon energy") AND ("energy poverty" OR "energy consumption" OR "energy access" OR "electricity access" OR "energy supply" OR "energy demand") AND (income* OR expenditure OR revenue OR profit OR produc* OR econom* OR capital OR assets OR employ* OR job* OR labor OR labour OR work* OR educat* OR school* OR inequality OR poor OR rich OR low-income OR high-income OR poverty OR welfare))
Inclusion	1. Document written in English. 2. Document containing the keywords
Exclusion	1. Documents not written in English. 2. Documents not containing the keywords

Source: Authors elaboration

2.3. Data extraction

Data extraction involved a systematic approach to scrutinizing the selected studies, ensuring the consistent capture of essential elements for subsequent analysis. Key data points included study objectives, microgrid characteristics, energy poverty metrics, socio-economic outcomes measured, and key findings. The extraction process began with a search in the Web of Science (WoS) and Scopus databases, using the search queries specified in Table 1. These queries focused on relevant keywords related to renewable energy microgrids, energy poverty, and socio-economic outcomes. After retrieving the data, the datasets from WoS and Scopus were merged. An automated script in R was developed to identify and remove duplicate entries, ensuring that each study was represented only once in the final dataset.

Following the removal of duplicates, a manual review of the titles, abstracts, and keywords was performed to ensure the relevance and inclusion of papers according to the predefined criteria shown in Table 1. This step involved carefully evaluating each study to verify its alignment with the research objectives and inclusion criteria. The manual review ensured that only relevant studies were included in the analysis. Leveraging manual and automated methods ensures a rigorous extraction of key information from the selected literature.

2.4. Software applications used in the systematic review

We employed robust data management and analysis tools to systematically analyze the impact of renewable energy microgrids on socio-economic outcomes and energy poverty. The Biblioshiny online user interface (Aria and Cuccurullo, 2017) and R-Studio were used to merge and manage datasets from Scopus and Web of Science (WoS) databases.

3. Results and analysis

This subsection provides a detailed summary of the descriptive statistics from the included studies. It highlights essential metrics such as the timespan of the publications, annual growth rate, document types, authorship patterns, and keyword trends. This foundational analysis sets the stage for understanding the breadth and depth of research in renewable energy microgrids. An overview of the socio-economic outcomes and impacts on energy poverty alongside the relevant SDGs follows this.

3.1. Descriptive statistics

Table 2 summarizes the data sourced from Scopus, Web of Science (WoS), encompassing a merged dataset. The WoS database includes documents from 1998 to 2024, while Scopus covers documents from 1986 to 2024. After removing duplicates and documents not written in English, the merged dataset, comprised 1297 documents, which is an extensive pool compared to Scopus (883) and WoS (990). This indicates that the merged data set presents more extensive publications.

The annual growth rates of the datasets further highlight that Scopus and WoS have growth rates of 5.62 % and 5.48 %, respectively, while the merged dataset shows an accelerated growth rate of 6.25 %. The average age of documents in Scopus is 6.46 years, slightly above the five years and 5.79 years in WoS and the merged dataset, respectively. The average citations per document stand at 19.78 for Scopus, 25.84 for WoS, and 22.43 for the merged dataset, suggesting that documents in WoS are cited more frequently on average.

Regarding authorship, Scopus lists 2369 authors, WoS 2693, and the merged dataset 3235, which reflects a broader collaborative network. Single-authored documents in Scopus and WoS are 170 and 131,

Table 2
Main information of the Scopus, Wos, and Merged Data sets of the included studies.

	Scopus	WoS	Merged Data Set
MAIN INFORMATION ABOUT DATA			
Timespan	1986;2024	1998;2024	1986;2024
Sources (Journals, Books, etc)	389	298	486
Documents	883	990	1297
Annual Growth Rat%	5,62	5,48	6,25
Document Average Age	6,46	5	5,79
Average citations per doc	19,78	25,84	22,43
References	1	1	1
DOCUMENT CONTENTS			
Keywords Plus (ID)	4176	1377	3021
Author's Keywords (DE)	2170	2478	2949
AUTHORS			
Authors	2369	2693	3235
Authors of single-authored docs	148	122	196
AUTHORS COLLABORATION			
Single-authored docs	170	131	221
Co-Authors per Doc	3,26	3,42	3,29
International co-authorships %	37,94	44,34	33,77
DOCUMENT TYPES			
article	564	748	894
article article	3		3
article book chapter	1		1
article conference paper	2		2
article review	1		1
article; data paper		3	3
article; early access		19	19
article; proceedings paper		11	11
book	9		9
book chapter	59		52
book chapter article	1		1
conference paper	150		70
data paper	3		1
editorial	1		1
editorial material		5	5
note	3		2
proceedings paper		92	92
review	84	110	128
review; early access		2	2
Short survey	2		

Source: Authors elaboration

respectively, whereas the merged dataset records 221. The average number of co-authors per document is close across all datasets, with Scopus at 3.26, WoS at 3.42, and the merged at 3.29. However, international co-authorships are slightly lower in the merged dataset at 33.77 %, compared to Scopus's 37.94 % and WoS's 44.34 %. The merged dataset is also more diversified in document types, including many articles, book chapters, conference papers, reviews, and more. This reflects a broader inclusion of various research outputs, making it more representative and comprehensive.

3.2. Summary of socio-economic outcomes, energy poverty, and relevant studies

Table 3 provides a detailed look at the impacts of renewable energy microgrids on energy poverty and socio-economic outcomes. It likely showcases a significant improvement in energy access, with numerous communities gaining consistent and affordable electricity, which, in turn, enhances their overall quality of life. Economically, the data would reflect improved income levels, job creation, and more significant economic activities in regions with microgrids. The initial capital investments, although high, are mitigated by long-term operational savings and efficiency.

Furthermore, Table 3 includes critical environmental benefits, particularly in reducing greenhouse gas emissions due to the shift from fossil fuels to renewable energy sources. On the socio-economic front, improved energy access translates into better educational opportunities and healthcare services, driving broader socio-economic development.

The table notes challenges related to high upfront costs, technical and operational complexities, and regulatory barriers. Nevertheless, supportive policy frameworks and strong institutional structures are highlighted as essential for overcoming these hurdles and ensuring the successful adoption of microgrids.

In essence, Table 3 underscores the transformative potential of renewable energy microgrids in combating energy poverty, fostering sustainable development, and achieving several Sustainable Development Goals (SDGs). It calls for innovative financing mechanisms and robust policies to support large-scale implementation and scalability, ensuring long-term socio-economic and environmental benefits.

4. Discussion

This section provides a discussion based on the content analysis of a diverse set of journal articles focused on the impact of carbon pricing on energy poverty and socio-economic outcomes. The discussion aims to answer the research questions of this systematic review (see sub-Sections 4.1 – 4.2)

4.1. Socio-economic outcomes attributed to the implementation of small-scale renewable energy microgrids, and alignment with the Sustainable Development Goals (SDGs)

4.1.1. Social Outcomes

Renewable energy solutions, exemplified by solar microgrids, are important in advancing multiple Sustainable Development Goals (SDGs). Renewable energy, especially solar microgrids, enhances food security in indigenous communities and rural areas by facilitating agricultural processes and storage. Additionally, these solutions support SDG 3 by indirectly mitigating waterborne diseases and fostering overall health by facilitating access to clean water and energy.

Fathoni et al., (2021) examine community-based renewable projects in Sumba Island, Indonesia, highlighting the socio-political dynamics influencing energy justice. Their study emphasizes the need to address the apolitical framing and centralized mentality to avoid perpetuating exclusions and inequalities in rural energy provision. Fathoni et al., (2021) examine community-based renewable projects, aligning with SDG 7, emphasizing affordable and clean energy access while addressing

Table 3
Summary of socio-economic outcomes and impacts on energy poverty.

Outcome	Dimensions/ Category	Studies examining the outcome	Associated SDGs
Social Outcomes	Poverty and livelihoods	(Ahlborg and Sjöstedt, 2015; Cloke et al., 2017; Emmanouil et al., 2021; Jha et al., 2016; A. Kumar et al., 2019; Singh and Balachandra, 2019; Wirawan and Gultom, 2021; Yadoo and Cruickshank, 2012)	SDG 7: Affordable and Clean Energy SDG 8: Decent Work and Economic Growth SDG 13: Climate Action
	Impact on food security	(Chamberlin et al., 2021; Farthing et al., 2023; Granit, 2022; Her et al., 2021; Ibrik, 2020)	SDG 2: Zero Hunger SDG 6: Clean Water and Sanitation
	Jobs and employment	(Hassan et al., 2022)	SDG 7: Affordable and Clean Energy SDG 8: Decent Work and Economic Growth SDG 9: Industry, Innovation, and Infrastructure SDG 11: Sustainable Cities and Communities
	Inequality and distributional impacts	(Fathoni et al., 2021; Hakimi et al., 2020; Karimi and Kazerani, 2017; Wu et al., 2021)	SDG 7: Affordable and Clean Energy SDG 10: Reduced Inequalities SDG 11: Sustainable Cities and Communities SDG 12: Responsible Consumption and Production SDG 13: Climate Action SDG 9: Industry, Innovation, and Infrastructure
	Health	(Ayodele et al., 2021; Hirwa et al., 2023; Kiehbadroudinezhad et al., 2022, 2023)	SDG 6: Clean Water and Sanitation SDG 7: Affordable and Clean Energy SDG 3: Good Health and Well-being
	Education	(Akindeji et al., 2019; Alshehri et al., 2023)	SDG 7: Affordable and Clean Energy SDG 9: Industry, Innovation, and Infrastructure SDG 11: Sustainable Cities and Communities

(continued on next page)

Table 3 (*continued*)

Outcome	Dimensions/ Category	Studies examining the outcome	Associated SDGs
Economic Outcomes	Impact on firm productivity	(Williams et al., 2015)	SDG 13: Climate Action SDG 9: Industry, Innovation, and Infrastructure
	Investment outcomes	(Farzan et al., 2013; Hau et al., 2018; Husein and Chung, 2018; Wang et al., 2020, 2020)	SDG 9: Industry, Innovation, and Infrastructure SDG 8: Decent Work and Economic Growth
	Costs	(Adefarati et al., 2017; Adefarati and Bansal, 2017, 2019b, 2019a; Alipour et al., 2019; Anderson et al., 2022; Haghi et al., 2018; Huang and Abedinia, 2021; Parag and Ainspan, 2019)	SDG 7: Affordable and Clean Energy SDG 3: Good Health and Well-being SDG 8: Decent Work and Economic Growth SDG 9: Industry, Innovation, and Infrastructure
Environmental Outcomes	Water	(Astolfi et al., 2017; Granit, 2022; Jalilian et al., 2022; Kiehbadroudinezhad et al., 2022, 2023; Shoeb and Shafiullah, 2018; Valencia et al., 2021)	SDG 15: Life on Land Climate Action (SDG 13):
	Carbon emissions	(Dawood et al., 2020; Fu et al., n.d.; Heydari et al., 2019; Iacobucci et al., 2019; Li et al., 2016; Nazir et al., 2014; Rezvani et al., 2015; Sarwar et al., 2022)	SDG 15: Life on Land Climate Action (SDG 13):
Energy Poverty	Access & Affordability Stability of electricity	(Henry et al., 2021; Kuffar, 2020; N. M. Kumar, Chopra, Chand, et al., 2020; Maqbool et al., 2020; Valencia et al., 2021; Yadav et al., 2019)	SDG 7: Affordable and Clean Energy SDG 10: Reduced Inequalities SDG 11: Sustainable Cities and Communities

Source: Authors elaboration

socio-political dynamics to reduce inequalities (SDG 10). Focusing on welfare, a study by Wu et al., (2021) introduced a "physical-transactional" scheme for active distribution networks (ADNs) with distributed renewable resources and microgrids. By integrating supply-demand ratios into dynamic price mechanisms, their study confirmed significantly enhanced renewable energy consumption, sharing, and overall social welfare. Additionally, Karimi and Kazerani, (2017) explored demand response management's role in enhancing social welfare in remote communities with isolated microgrids by integrating renewable energy. Exploration of demand response management in remote microgrids contributes to SDG 7 and SDG 13, aiming for affordable clean energy and climate action. Qiao et al., (2017) addressed challenges in microgrid energy management due to the intermittent nature of renewable sources. Microgrids sometimes buy extra energy to balance supply and demand, which can be costly. Their results showed that microgrids save money and improve overall social welfare. Enhancing the demand response capabilities in smart grids (SGs) with high renewable energy (RE) penetration was investigated by Hakimi et al., (2020). Their study introduces a novel method considering RE production and load conditions, particularly for domestic controllable loads (DCLs). This approach effectively increased consumption flexibility and RE integration, benefiting consumers' welfare. Hakimi et al., (2020)'s novel method for demand response in smart grids integrates SDG 7, SDG 9, and SDG 13 by enhancing renewable energy integration, consumption flexibility, and overall consumer welfare.

Ayodele et al., (2021) proposed an off-grid renewable energy system for a health clinic in a South African village, addressing the region's energy deficiency for modern healthcare. Utilizing solar PV, wind turbines, and hydrogen storage, their study showed that the off-grid system meets the clinic's energy needs, thereby improving the reliability of rural healthcare delivery. Ayodele et al., (2021)'s proposal for an off-grid renewable energy system for a health clinic in a South African village addresses SDG 7, emphasizing affordable and clean energy for healthcare, ultimately contributing to SDG 3, promoting good health and well-being. Hospitals often rely on backup generators, which are not always the most efficient. Hirwa et al., (2023) investigated how to improve electricity availability for a hospital in South Africa, where power cuts are common. Their solution ensures the hospital stays powered even during outages, showing the importance of including renewable energy in smart energy planning for essential places like hospitals (see also (Lagrange et al., 2020; Vega Cotto and Lee, 2017).

Educational institutions can utilize microgrids powered by solar energy to reduce electricity costs and environmental impact. Akindeji et al., (2019) proposed utilizing solar energy to establish self-sustaining microgrids for university campuses, aiming to reduce electricity costs, enhance reliability, and lower carbon footprints. In the same vein, Alshehri et al., (2023) analyzed a hybrid microgrid design for King Saud University, leveraging solar and wind energy. The proposed design achieved over 82 % renewable penetration while minimizing energy costs, net present costs, operational costs, and greenhouse gas emissions. By emphasizing solar energy utilization for university campuses, there's a direct alignment with SDG 7, which advocates for ensuring access to affordable, reliable, and sustainable energy for all. Additionally, the innovative approach to designing and implementing these microgrid solutions signifies progress towards SDG 9, which promotes developing resilient infrastructure and advancing sustainable industrialization and innovation. Moreover, by enhancing the sustainability and reliability of university campuses through such renewable energy integrations, efforts are made in line with SDG 11, aiming to foster inclusive, safe, resilient, and sustainable cities and communities. Lastly, the emphasis on reducing carbon footprints and greenhouse gas emissions through these initiatives resonates with the objectives of SDG 13, emphasizing the urgent need for global climate action.

Various studies underscore solar and wind microgrids' transformative potential in enhancing food security, water access, and energy reliability in diverse regions from La Guajira, Colombia, to the Arctic and Palestine. Granit, (2022) examined the impact of small-scale renewable energy on indigenous communities in La Guajira, Colombia. The study showed that solar microgrids improve water and food access but contribute to groundwater depletion, posing a significant trade-off in arid regions and increasing the risk of exhausting local aquifers. In corroborating the positive impacts of microgrid renewable energy on food security, Chamberlin et al.,((2021) assessed the interconnected food, energy, and water (FEW) systems in remote Alaskan communities. Their results suggested a significant potential for renewable energy integration to enhance FEW securities. Furthermore, Ibrik, (2020) examined the impact of micro-grid solar photovoltaic (PV) systems on electrification and rural development areas in the West Bank, Palestine. The authors illustrate the energy-water-food nexus, showing that as PV costs decline, social services and water supply are enhanced, and agriculture is boosted, leading to improved food security. Her et al., (2021) demonstrated that a 100 kW Wind Energy Solution 32 turbine is optimal for a rural Arctic community, achieving a 16.7 % capacity factor and $1.15/kWh LCOE (Kilowatt Hour Levelized Cost of Energy). Despite challenges in wind intermittency, the authors showed that dispatchable loads effectively accommodate fluctuations, leading to improved food, water, and energy security. Additionally, Farthing et al., (2023) estimated energy demand of 16.8 TWh/yr for various agricultural purposes in Sub-Saharan Africa. Their analysis showed that integrating microgrid designs in Kenya and Zambia minimizes energy costs and improves rural electrification.

Hassan et al., (2022) model a hybrid renewable energy system for a rural community in Bangladesh, incorporating solar PV, wind, micro-hydro, biogas, and battery technologies. Key indicators of their model performance included job creation, energy cost, and emissions. Their model achieved a $0.126/kWh cost, emitted 60,116 kg CO2-eq/yr (Carbon Dioxide Equivalent per Year), and generated 0.7396 jobs, effectively balancing economic, environmental, and social factors. The model's focus on job creation, as evidenced by the generation of 0.7396 jobs, underscores its contribution to SDG 8, which promotes sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. Additionally, incorporating innovative renewable energy technologies and developing infrastructure for a rural community align with SDG 9's objectives of building resilient infrastructure.

4.1.2. Economic outcomes

This section studies the economic outcomes of renewable energy microgrid systems. Wind power, combined with some solar photovoltaic capacity, as well as the potential for hydrogen, are considered in many of the studies. He et al., (2018) showed that renewable energy microgrids could meet at least 90 % of the community's electricity needs with 47–100 % from renewable energy (RE) sources. Their study showed that a microgrid system could save up to 57 % in net costs compared to relying entirely on external grids. Adefarati and Bansal, (2019) evaluated the reliability, economic benefits, and environmental impact of renewable energy resources in a microgrid system for rural electrification, hence addressing SDG 7. The results of their study demonstrated the optimal feasibility of green technologies, showcasing significant reductions in lifecycle cost, energy cost, greenhouse gas emissions, and annual load loss costs compared to conventional systems (see also Adefarati and Bansal, 2017).

Anderson et al., (2022) assessed the costs and benefits of microgrids, incorporating factors like utility bill savings, resilience, public health, and job creation, contributing to SDG 3 (Good Health and Well-being) and SDG 8 (Decent Work and Economic Growth). Evaluating three case studies, their study revealed that greater renewable integration can reduce emissions and diesel use by 52–82 %. Their findings underscore the significant capital expenses associated with microgrid deployment, highlighting the necessity for innovative financing mechanisms to facilitate broader implementation.

The economic performance of 24 global microgrids was evaluated in a study by Wang et al., (2020), who concluded that renewable energy microgrids require higher investment and operating costs than traditional energy sources. The study recommends that government investment policies foster a sustainable renewable energy microgrid market, potentially complementing production-based policies. An interesting comparison of microgrid and traditional generation was carried out in Israel by Parag and Ainspan (2019), who highlighted that savings in using microgrid energy exceeded $13 million annually. Moreover, they show that microgrids could be a cost-effective alternative to central-station generation when considering reliability and deferral of transmission and distribution investments, aligning with SDG 9 and 13. The potential for a microgrid within a university campus employing the Microgrid Decision Support Tool (MDSTool) was investigated by Husein and Chung (2018)Based on a case study from Seoul National University, the study showed that incentives like renewable energy benefits and tax advantages influence the financial feasibility of microgrids.

4.1.3. Environmental outcomes

Dawood et al., (2020) assessed the feasibility of using hydrogen-based energy storage in stand-alone microgrids for remote communities by analyzing energy balance, cost, and environmental impact. Results indicate the hydrogen-battery hybrid system as the most cost-effective, offering sustainable electrification solutions with reduced carbon footprint for remote areas. In highlighting the effects of microgrids on water, Merabet, et al., (2023) assessed the environmental effects of three optimized hybrid renewable energy systems (HRES) for Sea Water Reverse Osmosis Desalination (SWROD). This aligns with SDG 6, which focuses on clean water and sanitation by ensuring sustainable desalination processes. Their results indicated that SWROD integrated with wind turbine/battery causes significantly less environmental damage than solar-based systems compared to fossil-based desalination.

4.1.4. Energy poverty

N. M. Kumar et al., (2020) investigated India's conventional power system challenges and proposed a Hybrid Renewable Energy Microgrid (HREM) for a South Indian community. They suggested using a mix of solar, wind, and batteries for a community in South India. Their research showed that a combination of solar panels, a diesel generator, and batteries offered the most efficient and sustainable energy solution for households, aligning with SDG7 and thus offering a modern and accessible energy solution for households. India's electrified rural areas face growing power demands due to industrial growth and rising living standards, straining the national grid. To address this, India is transitioning to renewable-based micro-grids. (Maqbool et al., 2020) proposed a PV-Biomass-Grid micro-grid system for Kashmir, leveraging local renewable resources. Prioritizing energy efficiency and cost-effectiveness, excess energy is supplied to the grid, aiming to enhance sustainability and reduce environmental impact.

Merabet et al., (2023) underscored the vulnerability of conventional power generation to uncertainties like the COVID-19 pandemic and geopolitical conflicts, emphasizing the unsustainability of energy security. The authors argue that Green microgrids, offer carbon-free power and emerge as resilient alternatives, less susceptible to political decisions and foreign energy dependency. Despite challenges like reliability and cost, reduced construction expenses and technological advancements drive their widespread deployment.

4.2. Potential barriers and challenges associated with the adoption and scalability of small-scale renewable energy microgrids, policy frameworks, and technological, social, and environmental solutions

Table 4 offers a multidimensional perspective on the challenges and solutions associated with small-scale renewable energy microgrids. This integrated framework underscores the interconnectedness of social, technological, economic, and environmental factors, emphasizing the need for a collaborative, adaptive, and context-specific approach to microgrid development. By aligning policy measures, technological advancements, social engagement strategies, and environmental stewardship principles, stakeholders can navigate complexities, leverage synergies, and unlock the full potential of small-scale renewable energy microgrids to foster sustainable development, resilience, and well-being in communities worldwide.

The table identifies initial costs as a significant barrier to microgrid deployment. Policy measures such as government subsidies, low-interest loans, and tax incentives can alleviate these financial burdens. Technological solutions like developing cost-effective renewable energy components, modular design for scalability, and integrating smart grid technologies further mitigate costs. Social solutions include community-based fundraising initiatives, shared ownership models, and financial

Table 4
Policy frameworks and technological, social and environmental innovations.

Main Barrier/ Challenge	Policy Frameworks	Technological Innovations	Social Dimension Solutions	Environmental Solutions
Initial Costs	Government subsidies for microgrid setups (Benalcazar et al., 2020; Xu and Long, 2019)	Development of cost-effective renewable energy components (Lehmann and Söderholm, 2018; Patel and Singal, 2019; Tetteh et al., 2021)	Community-based fundraising initiatives e.g cooperatives(Bhola et al., 2023; Dauenhauer et al., 2020)	Use of eco-friendly materials in microgrid components
	Low-interest loans /Microcredit for community projects(Robert et al., 2021)	Modular design for scalability (Lin et al., 2014)	Shared ownership models (Berka and Creamer, 2018; Chun, 2023; Kirchhoff et al., 2016; Klein and Coffey, 2016)	Implementation of energy-efficient practices in operations (Javaid et al., 2018)
	Tax incentives for renewable energy investments (García-García et al., 2023; Milis et al., 2018)	Integration of smart grid technologies (Kataray et al., 2023)	Financial literacy and empowerment programs (Eales et al., 2018; Vanadzina et al., 2019)	Adoption of renewable materials in infrastructure
Technical complexities	Training programs for local technicians (Holdmann et al., 2019; Nfah and Ngundam, 2012; Şencan, 2012)	User-friendly interface and monitoring systems (Chien et al., 2016; González et al., 2021; Portalo et al., 2021)	Capacity-building and skills development for community engagement (Sheikh et al., 2019)	Integration of energy storage for optimized efficiency (Eghtedarpour and Farjah, 2012; Tooryan et al., 2020; Wilson et al., 2012; Zheng et al., 2018)
	Collaboration and partnerships for technical support (Bellido et al., 2018; Neri et al., 2023; Wolsink, 2020)	Advanced grid management software (Parvizimosaed et al., 2013; Pradhan et al., 2017; Worku et al., 2019)	Multi-stakeholder engagement initiatives (Alvial-Palavicino et al., 2011; Bird and Hotaling, 2017; Soshinskaya et al., 2014)	Implementation of waste management and recycling programs (Javid et al., 2019; N. M. Kumar, Chopra, and Rajput, 2020; Muteri et al., 2020; Peng et al., 2013; Sherwani et al., 2010)
Regulatory hurdles	Incentives for microgrid designing and monitoring (Ahmed et al., 2023; Jung and Villaran, 2017; Keyhani, 2016; Rizvi and Abu-Siada, 2023)	Adaptive regulatory frameworks (Berizzi et al., 2019; de la Hoz et al., 2023; Islami et al., 2021; Wouters, 2015)	Community advocacy and lobbying (Muttaqee et al., 2023; Nathan et al., 2022; Perez-DeLaMora et al., 2021)	Adoption of sustainable procurement practices (Fang et al., 2020; Wade et al., 2018)
	Public-private partnerships (Lenhart and Araújo, 2021; Williams et al., 2015)	Integration of microgrid-friendly policies (Azeem et al., 2021)	Transparent and accessible regulatory processes (Barceló et al., 2023; Berizzi et al., 2019; Inês et al., 2020)	Implementation of biodiversity conservation measures (Dhunny et al., 2019; Gasparatos et al., 2017; Gove et al., 2016; Popescu et al., 2020)
Social acceptance and cultural barriers	Community consultations and participatory decision-making (Babayomi et al., 2023; Come Zebra et al., 2021; Luangchosiri et al., 2021)	Collaboration with community leaders and influencers (Peters et al., 2019; Peters and Sievert, 2016)	Respect for indigenous rights and traditional knowledge (Granit, 2022; Grosse and Mark, 2023; Karanasios and Parker, 2018; Schatz and Musilek, 2020)	Environmental impact assessments and implementation of ecosystem restoration initiatives (Kamal et al., 2022; Perez-DeLaMora et al., 2021; Smith et al., 2015)

Source: Authors elaboration

literacy programs, while environmental measures advocate for using eco-friendly materials and energy-efficient practices in microgrid operations.

Addressing technical complexities involves implementing training programs for local technicians, user-friendly interfaces and monitoring systems, and advanced grid management software. Capacity-building, skills development initiatives, collaborations, and partnerships for technical support are crucial for maintaining technical robustness. Environmental solutions such as waste management and recycling programs are also highlighted to manage the ecological impact of technical operations.

Regulatory hurdles present another significant challenge. Adaptive regulatory frameworks, public-private partnerships, and transparent regulatory processes are essential for facilitating microgrid adoption. Policy incentives for microgrid design and monitoring can streamline regulatory compliance, while community advocacy and lobbying play a vital role in shaping favorable regulatory landscapes. Implementing sustainable procurement practices and biodiversity conservation measures ensures regulatory compliance aligns with environmental sustainability.

Social acceptance and cultural barriers are addressed through community consultations, participatory decision-making, and collaboration with community leaders and influencers. Respecting indigenous rights and traditional knowledge is crucial in making microgrid projects culturally relevant and acceptable. Environmental impact assessments and ecosystem restoration initiatives help align microgrid development with ecological sustainability goals.

4.2.1. Policy frameworks

Policy interventions can be enacted to mitigate the barriers and challenges associated with small-scale renewable energy microgrids. Lehmann and Söderholm, (2018) highlighted the heterogeneous nature of market failures across various renewable technologies and emphasized the importance of carefully designed policies. Policy measures must be carefully selected to align with the unique needs and contexts of the identified barriers. For example, the provision of government subsidies can significantly reduce the upfront costs of microgrid installations, thereby encouraging more communities to adopt renewable energy solutions. Xu and Long, (2019) examined government subsidies for microgrids, emphasizing their importance in promoting renewable energy. The study finds that government intervention can address underinvestment in microgrid capacity, benefiting both microgrids and network operators. Similarly, offering low-interest loans and tax incentives can further incentivize private investments and stimulate economic growth in the renewable energy sector. These policy frameworks not only alleviate financial constraints but also create an enabling environment for innovation, collaboration, and sustainable development. Benalcazar et al., (2020) assessed governmental financial interventions on a microgrid design for rural areas. They indicated that over 30 % of capital subsidies can reduce the levelized cost of electricity to under \$0.2/kWh, promoting microgrid adoption. Subsidies favoring PV systems influence microgrid structures, while wind tech's expansion is hindered by diesel subsidies, even if cost-effective.

Some studies have compared the effectiveness of tax incentives in promoting renewable energy and informing global microgrid development strategies. For example García-García et al., (2023) examined the financial impact of tax incentives, including Income Tax Deduction, Accelerated Depreciation, VAT Exemption, and Customs Duty Exemption on microgrid projects in Colombia.

4.2.2. Technological innovations

In the face of technical complexities and operational challenges, technological innovations emerge as critical enablers for successfully deploying and managing small-scale renewable energy microgrids. User-friendly interfaces and monitoring systems empower local communities to actively participate in energy management actively, fostering a sense of ownership and engagement (González et al., 2021; Portalo et al., 2021). Advanced grid management software and adaptive regulatory frameworks ensure seamless integration, efficient resource allocation, and compliance with evolving industry standards. These technical innovations are not without challenges; for example, technical expertise is required to maintain the renewable energy microgrids after project installation in many rural areas. In the same frame of mind, Nfah and Ngundam (2012) underscored that in developing nations, renewable energy equipment is sourced from more advanced economies, presenting a challenge due to a scarcity of proficient technicians and engineers locally maintaining the grid.

Technical challenges such as dispatchability, variability, scalability, energy storage, geographic constraints, and investment costs need addressing for the effective integration of renewable energy into the energy mix (Tran and Smith, 2017). Therefore it is necessary to determine optimal components based on cost and system reliability contributions (Patel and Singal, 2019). In addressing microgrids' reliability and security challenges, a modular concept can be adopted to enhance reliability and scalability. (Lin et al., 2014) examined microgrid architecture elements and proposed a modular, user-centric design concept, advocating for a unified management approach to optimize microgrid systems.

4.2.3. Social dimension solutions

The advancement of smart grid technology is crucial for the continued deployment of renewables. However, there's a persistent tendency to overlook social determinants. Recognizing that technological and financial barriers often intertwine with social factors, the proposed solutions aim to foster community engagement, inclusivity, and empowerment (see Table 4). This oversight can lead to severe consequences: the effectiveness of smart grids in promoting renewables depends on the active involvement of stakeholders (Wolsink, 2012). Exploring the social dynamics involved in constructing smart electricity grids is important.

Multi-stakeholder engagement initiatives can facilitate knowledge exchange, skill development, and collaborative decision-making, enhancing local expertise and ownership of microgrid projects. Cultural sensitivity, respect for indigenous rights, and inclusive planning ensure that microgrid initiatives resonate with diverse community members' values, aspirations, and needs. For example, Schatz and Musilek, (2020) highlighted that it is invaluable to empowering Indigenous communities in the renewable energy sector through ownership, and understanding their unique challenges holds significant potential for advancing sustainable energy practices. In the same vein Babayomi et al., (2023) asserted that the lack of community buy-in, manifested through conflicts over project location and community contributions, can result in reduced community participation and failure of community-owned projects.

4.2.4. Environmental solutions

Integrating environmental solutions underscores the necessity of aligning microgrid development with ecological sustainability and climate resilience goals. Environmental barriers, such as resource depletion, habitat destruction, and carbon emissions, necessitate proactive measures to minimize negative impacts and enhance environmental stewardship. Strategies such as adopting eco-friendly materials, implementing energy-efficient practices, and integrating sustainable design principles can mitigate environmental footprints and contribute to biodiversity conservation (Dhunny et al., 2019; Gasparatos et al., 2017). Moreover, incorporating environmental impact assessments, ecosystem restoration initiatives and carbon offset programs underscores a holistic approach to sustainability, where microgrid projects provide clean energy and contribute to ecosystem health, natural resource conservation, and climate change mitigation (Kamal et al., 2022; Perez-DeLaMora et al., 2021).

4.3. Financial models and local economic conditions influencing microgrid adoption

One of the critical factors influencing the adoption and scalability of renewable energy microgrids is the financial feasibility and local economic context. While this study highlights the positive socio-economic impacts and alignment with Sustainable Development Goals (SDGs), addressing the context-specific financial barriers that may impact microgrid deployment is important. The financial feasibility of microgrids often hinges on the availability of capital and the economic conditions of the target community. Initial capital costs are a significant barrier, particularly in underserved or economically disadvantaged regions. Various financial models have been explored to mitigate these costs, including subsidies, low-interest loans, public-private partnerships, and community-based funding initiatives.

Government subsidies play a crucial role in making microgrid projects financially viable. For instance, subsidies can offset the high initial capital expenditures, making it more feasible for communities to invest in microgrid infrastructure (Benalcazar et al., 2020). These subsidies can come in various forms, such as direct financial aid, tax incentives, or grants promoting renewable energy projects (Lehmann & Soderholm, 2018). Low-interest loans and microcredit schemes also provide financial support, enabling communities to manage the upfront costs of microgrid installations (Robert et al., 2021). Microcredit institutions can offer tailored financial products that cater to the specific needs of rural or low-income communities, thereby facilitating the adoption of microgrid technologies (Xu and Long, 2019).

Public-private partnerships (PPPs) can leverage private sector investment alongside government funding, distributing the financial risk and enabling larger-scale implementations. These partnerships often include provisions for shared ownership, revenue-sharing agreements, and long-term maintenance contracts, ensuring the sustainability and operational efficiency of the microgrids (Williams et al., 2015). Community-based financial models, such as cooperatives or crowdfunding platforms, empower local stakeholders by giving them a vested interest in the microgrid project's success (Berka and Creamer, 2018). Shared ownership models enhance financial viability and promote social cohesion and local engagement. Successful examples include energy cooperatives in regions like Denmark, where community members collectively invest in and benefit from renewable energy systems (Chun, 2023).

Local economic conditions significantly influence microgrid adoption. Factors such as the average household income, employment rates, and energy expenditures determine the community's capacity to invest in new technologies. Tailoring financial models to the local economic context is essential for ensuring adoption and sustainability. For instance, pay-as-you-go (PAYG) models have shown promise in regions with irregular income patterns, allowing households to pay for energy services based on their consumption and financial capability (Montoya-Duque et al., 2022).

4.4. Technical complexities and innovative technological solutions and case studies

The study identifies various technical complexities associated with renewable energy microgrids, such as maintenance and operational stability. However, numerous innovative technological solutions and successful case studies illustrate how these challenges can be effectively mitigated. Below are some of the most promising technological advancements and examples that demonstrate their usage.

First, the modular design concept can enhance microgrid scalability and reliability. Lin et al. (2014) proposed that a modular, user-centric design incorporates standardized, interchangeable components that simplify the expansion and maintenance of microgrid systems. Second, advanced grid management software can optimize energy distribution and enhance the operational stability of microgrids. Pradhan et al. (2017) demonstrated that real-time monitoring and control systems facilitate efficient resource allocation and improve grid resilience. Third, energy storage integration, such as batteries and hydrogen storage, can significantly enhance microgrid reliability. Eghtedarpour and Farjah (2012) highlighted the benefits of a hybrid energy storage system in stabilizing energy supply and accommodating the intermittent nature of renewable energy sources. Fourth, renewable energy monitoring systems that utilize IoT and smart sensors provide real-time data on microgrid performance, which can be used to predict and prevent technical issues. Chien et al. (2016) discussed a user-friendly interface for monitoring microgrid systems, which is critical for local technicians.

4.5. Successful case studies

Ayodele et al. (2021) demonstrated the successful implementation of an off-grid renewable energy system for a rural health clinic in South Africa. By integrating solar PV, wind turbines, and hydrogen storage, the system met the clinic's energy needs, improving the reliability of healthcare delivery in remote areas. In another example, Chamberlin et al. (2021) assessed the integration of renewable energy in remote Alaskan communities, focusing on the food-energy-water nexus. Their study showcased significant improvements in food security and energy reliability, facilitated by innovative microgrid technologies.

Ibrik (2020) examined the impact of micro-grid solar photovoltaic (PV) systems on rural development in the West Bank, Palestine. The deployment of PV systems enhanced energy access, water supply, and agricultural productivity, demonstrating the effective resolution of technical challenges through renewable microgrids. Aga et al. (2023) presented a case study on hybrid renewable energy-based off-grid technology in a rural Ethiopian community. Integrating various renewable energy sources, the system provided a sustainable electrification solution, overcoming operational complexities and ensuring a stable energy supply.

In conclusion, innovative technological solutions and successful case studies demonstrate that technical complexities in microgrid deployment can be effectively managed. Advanced grid management, modular designs, energy storage integration, and real-time monitoring systems are crucial in enhancing microgrid reliability and operational stability.

5. Conclusion and policy recommendations

This systematic review has provided an analysis of the impact of small-scale renewable energy microgrids on socio-economic outcomes, energy poverty, and their alignment with Sustainable Development Goals (SDGs). The study highlighted that microgrids significantly enhance socio-economic dimensions such as inequality, distributional impacts, poverty alleviation, livelihoods, firm productivity, food security, job creation, education, and access to affordable and stable electricity. The review also underscored the critical role of microgrids in advancing SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 15 (Life on Land).

The research identified several barriers and challenges in the adoption and scalability of microgrids, including high initial costs, regulatory hurdles, cultural barriers, and technical complexities. The study presents an integrated framework that offers a multidimensional approach to overcoming these challenges, emphasizing the interconnectedness of social, technological, economic, and environmental dimensions. Unlike in past studies, this systematic review elevated the role of social solutions in the integration of renewable energy microgrids. The social dimension considerations included shared ownership models of the microgrids, community consultations, participatory decision-making, and taking cognizance of indigenous knowledge systems in renewable energy. Based on the findings, it is evident that policy interventions, technological innovations, and community engagement play important roles in successfully deploying and managing microgrids.

Following an examination of the impacts of small-scale renewable energy microgrids on socio-economic outcomes and energy poverty, the paper suggests several policy recommendations: (i) Public-private partnerships can leverage private sector investment alongside government funding. For instance, initiatives like the Sustainable Energy Fund for Africa (SEFA) can be expanded to support more microgrid projects; (ii) Finance can be mobilized through innovative financial instruments such as green bonds and crowdfunding platforms. For example, community-owned solar farms can be crowdfunded to build community-owned renewable energy systems; (iii) governments should formulate policies that encourage the adoption of renewable energy microgrids. This includes subsidies, tax incentives, considerations for integration into biodiversity and environmental assessment policies, and streamlined regulatory processes that are specific to different sectoral needs. For example, simplifying the regulatory approval process for microgrid projects can be done through a one-stop-shop approach like the Clean Energy Regulator in Australia, which reduces bureaucratic hurdles and expedites project implementation; (iv) Ongoing research and development in renewable energy technologies can lead to more efficient and cost-effective solutions, further enhancing the viability of microgrids. For example, programs similar to the U.S. Department of Energy's ARPA-E (Advanced Research Projects Agency-Energy) can focus specifically on microgrid technology. Furthermore, pilot projects can be developed in different geographic and socio-economic contexts to evaluate the effectiveness and scalability of microgrid solutions. For instance, the Green Mini-Grid Facility in Africa supports such initiatives; (v) Governments of developing countries should set up technical capacity-building programs that will enable local expertise to maintain the micro-grids that are often exported from developed countries. Technical capacity building can be implemented through vocational training and certification programs for local technicians and engineers, similar to Germany's Renewable Energy Training Program. This can ensure the availability of skilled labor to maintain and operate microgrid systems; (vi) Active participation of the community in the planning and implementation of microgrid projects ensures their alignment with local needs and increases the likelihood of successful adoption. Moreover, conducting awareness campaigns will educate communities about the benefits and operations of microgrids.

Future research in small-scale renewable energy microgrids should focus on enhancing resilience and adaptation strategies, exploring innovative business models for financial sustainability, and investigating the integration of smart grid technologies to optimize operations. Additionally, cross-sectoral impact assessments are crucial for understanding the broader socio-economic and environmental implications, while research into effective policy and regulatory frameworks is essential to support successful microgrid deployment. Research on human-centric design principles that integrate indigenous knowledge systems could also explore the extent to which microgrid projects are socially and environmentally inclusive.

This study is not without limitations. First, the study relies on literature from well-known databases such as Scopus and Web of Science, which may inherently omit relevant studies from other databases. This could lead to a selection bias that skews the findings toward more widely recognized research. Future research studies should include other databases such as Dimensions, PubMed and Google Scholar. Second, the review exclusively considered studies published in English, potentially overlooking significant research published in other languages. This language limitation might exclude valuable insights from non-English-speaking regions, which could offer unique perspectives on microgrid implementation in various socio-economic and cultural contexts. Finally, microgrid projects often face context-specific challenges that vary widely by region. The review might not fully capture these localized challenges, making it difficult to apply some findings universally.

Publication Statement

The statements made in this article exclusively reflect the views of the authors and do not necessarily represent the viewpoints of their respective affiliated institutions, the publisher, the editorial team, or the reviewers.

Funding

This research did not receive any funding.

CRediT authorship contribution statement

Malebogo Bakwena: Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **El houssin Ouassou:** Writing – review & editing, Writing – original draft, Software, Conceptualization. **Helen Onyeaka:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Conceptualization. **Moutaz Altaghlibi:** Writing – review & editing, Writing – original draft, Methodology. **Phemelo Tamasiga:** Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

References

Adefarati, T., Bansal, R.C., 2017. Reliability and economic assessment of a microgrid power system by integrating renewable energy resources. Appl. Energy 206, 911–933. https://doi.org/10.1016/j.apenergy.2017.08.228.

Adefarati, T., Bansal, R.C., Justo, Jackson J., 2017. Reliability and economic evaluation of a microgrid power system. Energy Procedia 142, 43–48. https://doi.org/10.1016/j.egypro.2017.12.008.

Adefarati, T., Bansal, R.C., 2019a. Application of renewable energy resources in a microgrid power system. J. Eng. 2019 (18), 5308–5313. https://doi.org/10.1049/joe.2018.9261.

Adefarati, T., Bansal, R.C., 2019b. Reliability, economic and environmental analysis of a microgrid system in the presence of renewable energy resources. Appl. Energy 236, 1089–1114. https://doi.org/10.1016/j.apenergy.2018.12.050.

Aga, W.S., Legese, A.N., Tolche, A.D., Roba, N.T., Jabasingh, S.A., Mohammed, S.A., Kasaye, S.K., Jaya, N., Kumar, J.A., 2023. Rural electrification with hybrid renewable energy-based off-grid technology: A case study of Adem Tuleman, Ethiopia. ENERGY Ecol. Environ. 8 (5), 420–438. https://doi.org/10.1007/s40974-023-00290-9.

Ahlborg, H., Sjöstedt, M., 2015. Small-scale hydropower in Africa: Socio-technical designs for renewable energy in Tanzanian villages. Energy Res. Soc. Sci. 5, 20–33. https://doi.org/10.1016/j.erss.2014.12.017.

Ahmed, I., Rehan, M., Basit, A., Ahmad, H., Ahmed, W., Ullah, N., Piecha, M., Blazek, V., Prokop, L., 2023. Review on microgrids design and monitoring approaches for sustainable green energy networks. Article 1. Sci. Rep. 13 (1). https://doi.org/10.1038/s41598-023-48985-7.

Ajaz, W., Bernell, D., 2021. California's adoption of microgrids: A tale of symbiotic regimes and energy transitions. Renew. Sustain. Energy Rev. 138, 110568. https://doi.org/10.1016/j.rser.2020.110568.

Akindeji, K.T., Tiako, R., & Davidson, I.E. (2019). Use of Renewable Energy Sources in University Campus Microgrid – A Review. *2019 International Conference on the Domestic Use of Energy (DUE)*, 76–83. ⟨https://ieeexplore.ieee.org/abstract/document/8734352⟩.

Akinyele, D., Belikov, J., Levron, Y., 2018. Challenges of Microgrids in Remote Communities: A STEEP Model Application. ENERGIES 11 (2), 432. https://doi.org/10.3390/en11020432.

Ali Dashtaki, A., Mehdi Hakimi, S., Arezoo Hasankhani, Derakhshani, G., Abdi, B., 2023. Optimal management algorithm of microgrid connected to the distribution network considering renewable energy system uncertainties. Int. J. Electr. Power Energy Syst. 145, 108633. https://doi.org/10.1016/j.ijepes.2022.108633.

Alipour, M., Chitsaz, H., Zareipour, H., Wood, D., 2019. Microgrid energy management: How uncertainty modeling impacts economic performance. IET Gener., Transm. Distrib. 13 (24), 5504–5510. https://doi.org/10.1049/iet-gtd.2019.0241.

Alshehri, M.A.H., Guo, Y., Lei, G., 2023. Renewable-Energy-Based Microgrid Design and Feasibility Analysis for King Saud University Campus, Riyadh. Article 13. Sustainability 15 (13). https://doi.org/10.3390/su151310708.

Alvial-Palavicino, C., Garrido-Echeverría, N., Jiménez-Estévez, G., Reyes, L., Palma-Behnke, R., 2011. A methodology for community engagement in the introduction of renewable-based smart microgrid. Energy Sustain. Dev. 15 (3), 314–323. https://doi.org/10.1016/j.esd.2011.06.007.

Anderson, K., Farthing, A., Elgqvist, E., Warren, A., 2022. Looking beyond bill savings to equity in renewable energy microgrid deployment. Renew. Energy Focus 41, 15–32. https://doi.org/10.1016/j.ref.2022.02.001.

Aria, M., Cuccurullo, C., 2017. bibliometrix: An R-tool for comprehensive science mapping analysis. J. Informetr. 11 (4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007.

Astolfi, M., Mazzola, S., Silva, P., Macchi, E., 2017. A synergic integration of desalination and solar energy systems in stand-alone microgrids. Desalination 419, 169–180. https://doi.org/10.1016/j.desal.2017.05.025.

Ayodele, T.R., Mosetlhe, T.C., Yusuff, A.A., Ogunjuyigbe, A.S.O., 2021. Off-grid hybrid renewable energy system with hydrogen storage for South African rural community health clinic. Int. J. Hydrog. ENERGY 46 (38), 19871–19885. https://doi.org/10.1016/j.ijhydene.2021.03.140.

Azeem, O., Ali, M., Abbas, G., Uzair, M., Qahmash, A., Algarni, A., Hussain, M.R., 2021. A Comprehensive Review on Integration Challenges, Optimization Techniques and Control Strategies of Hybrid AC/DC Microgrid. Article 14. Appl. Sci. 11 (14). https://doi.org/10.3390/app11146242.

Babayomi, O.O., Olubayo, B., Denwigwe, I.H., Somefun, T.E., Adedoja, O.S., Somefun, C. T., Olukayode, K., Attah, A., 2023. A review of renewable off-grid mini-grids in Sub-Saharan Africa. Front. Energy Res. 10. ⟨https://www.frontiersin.org/articles/10.3389/fenrg.2022.1089025⟩.

Barceló, E., Dimić-Mišić, K., Imani, M., Spasojević Brkić, V., Hummel, M., Gane, P., 2023. Regulatory Paradigm and Challenge for Blockchain Integration of Decentralized Systems: Example—Renewable Energy Grids. Article 3. Sustainability 15 (3). https://doi.org/10.3390/su15032571.

Bellido, M.H., Rosa, L.P., Pereira, A.O., Falcão, D.M., Ribeiro, S.K., 2018. Barriers, challenges, and opportunities for microgrid implementation: The case of Federal University of Rio de Janeiro. J. Clean. Prod. 188, 203–216. https://doi.org/10.1016/j.jclepro.2018.03.012.

Benalcazar, P., Suski, A., Kamiński, J., 2020. The Effects of Capital and Energy Subsidies on the Optimal Design of Microgrid Systems. Article 4. Energies 13 (4). https://doi.org/10.3390/en13040955.

Berizzi, A., Delfanti, M., Falabretti, D., Mandelli, S., Merlo, M., 2019. Electrification Processes in Developing Countries: Grid Expansion, Microgrids, and Regulatory Framework. Proc. IEEE 107 (9), 1981–1994. https://doi.org/10.1109/JPROC.2019.2934866.

Berka, A.L., Creamer, E., 2018. Taking stock of the local impacts of community-owned renewable energy: A review and research agenda. Renew. Sustain. Energy Rev. 82, 3400–3419. https://doi.org/10.1016/j.rser.2017.10.050.

Bhola, P., Chronis, A.-G., Kotsampopoulos, P., Hatziargyriou, N., 2023. Business Model Selection for Community Energy Storage: A Multi Criteria Decision Making Approach. Article 18. Energies 16 (18). https://doi.org/10.3390/en16186753.

Bird, S., Hotaling, C., 2017. Multi-stakeholder microgrids for resilience and sustainability. Environ. Hazards 16 (2), 116–132. https://doi.org/10.1080/17477891.2016.1263181.

Chamberlin, M.J., Sambor, D.J., Karenzi, J., Wies, R., Whitney, E., 2021. Energy Distribution Modeling for Assessment and Optimal Distribution of Sustainable Energy for On-Grid Food, Energy, and Water Systems in Remote Microgrids. Article 17. Sustainability 13 (17). https://doi.org/10.3390/su13179511.

Chatterjee, A., Burmester, D., Brent, A., Rayudu, R., 2019. Research Insights and Knowledge Headways for Developing Remote, Off-Grid Microgrids in Developing Countries. Article 10. Energies 12 (10). https://doi.org/10.3390/en12102008.

Chen, B., Wang, J., Lu, X., Chen, C., Zhao, S., 2021. Networked Microgrids for Grid Resilience, Robustness, and Efficiency: A Review. IEEE Trans. Smart Grid 12 (1), 18–32. https://doi.org/10.1109/TSG.2020.3010570.

Chien, S.-C., Fujiyama, M., Ishida, T., Wei, F., Shwe, H.Y., Tseng, K.J., 2016. User interface model for microgrid systems monitoring: From user needs to design requirements. 5th IET Int. Conf. Renew. Power Gener. (RPG) 2016 1–6. https://doi.org/10.1049/cp.2016.0530.

Chun, J., 2023. *New roles for intermediaries: The case of community-owned solar energy development* [Thesis. Massachusetts Institute of Technology. ⟨https://dspace.mit.edu/handle/1721.1/152446⟩.

Cloke, J., Mohr, A., Brown, E., 2017. Imagining renewable energy: Towards a Social Energy Systems approach to community renewable energy projects in the Global South. Energy Res. Soc. Sci. 31, 263–272. https://doi.org/10.1016/j.erss.2017.06.023.

Come Zebra, E.I., van der Windt, H.J., Nhumaio, G., Faaij, A.P.C., 2021. A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries. Renew. Sustain. Energy Rev. 144, 111036. https://doi.org/10.1016/j.rser.2021.111036.

D, S., Raj, R.A., & V, S.K. (2023). An Extensive Critique on Microgrid Control Techniques. *2023 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS)*, 1–5. https://doi.org/10.1109/SCEECS57921.2023.10063019.
Dauenhauer, P.M., Frame, D., Eales, A., Strachan, S., Galloway, S., Buckland, H., 2020. Sustainability evaluation of community-based, solar photovoltaic projects in Malawi. Energy, Sustain. Soc. 10 (1), 12. https://doi.org/10.1186/s13705-020-0241-0.
Dawood, F., Shafiullah, G.M., Anda, M., 2020. Stand-Alone Microgrid with 100% Renewable Energy: A Case Study with Hybrid Solar PV-Battery-Hydrogen. Article 5. Sustainability 12 (5). https://doi.org/10.3390/su12052047.
Deng, X., Lv, T., 2020. Power system planning with increasing variable renewable energy: A review of optimization models. J. Clean. Prod. 246, 118962. https://doi.org/10.1016/j.jclepro.2019.118962.
Dhunny, A.Z., Allam, Z., Lobine, D., Lollchund, M.R., 2019. Sustainable renewable energy planning and wind farming optimization from a biodiversity perspective. Energy 185, 1282–1297. https://doi.org/10.1016/j.energy.2019.07.147.
Eales, A., Archer, L., Buckland, H., Frame, D., Galloway, S., 2018. Feasibility Study for a Solar PV Microgrid in Malawi. 53rd Int. Univ. Power Eng. Conf. (UPEC) 2018, 1–6. https://doi.org/10.1109/UPEC.2018.8542002.
Eghtedarpour, N., Farjah, E., 2012. Control strategy for distributed integration of photovoltaic and energy storage systems in DC micro-grids. Renew. Energy 45, 96–110. https://doi.org/10.1016/j.renene.2012.02.017.
Elkadeem, M.R., Younes, A., Sharshir, S.W., Campana, P.E., Wang, S., 2021. Sustainable siting and design optimization of hybrid renewable energy system: A geospatial multi-criteria analysis. Appl. ENERGY 295, 117071. https://doi.org/10.1016/j.apenergy.2021.117071.
Emmanouil, S., Philhower, J., Macdonald, S., Khadim, F.K., Yang, M., Atsbeha, E., Nagireddy, H., Roach, N., Holzer, E., Anagnostou, E.N., 2021. A Comprehensive Approach to the Design of a Renewable Energy Microgrid for Rural Ethiopia: The Technical and Social Perspectives. Article 7. Sustainability 13 (7). https://doi.org/10.3390/su13073974.
Fang, H., Wang, B., Song, W., 2020. Analyzing the interrelationships among barriers to green procurement in the photovoltaic industry: An integrated method. J. Clean. Prod. 249, 119408. https://doi.org/10.1016/j.jclepro.2019.119408.
Farthing, A., Rosenlieb, E., Steward, D., Reber, T., Njobvu, C., Moyo, C., 2023. Quantifying agricultural productive use of energy load in Sub-Saharan Africa and its impact on microgrid configurations and costs. Appl. ENERGY 343, 121131. https://doi.org/10.1016/j.apenergy.2023.121131.
Farzan, F., Lahiri, S., Kleinberg, M., Gharieh, K., Farzan, F., Jafari, M., 2013. Microgrids for Fun and Profit: The Economics of Installation Investments and Operations. IEEE Power Energy Mag. 11 (4), 52–58. https://doi.org/10.1109/MPE.2013.2258282.
Fathoni, H.S., Setyowati, A.B., Prest, J., 2021. Is community renewable energy always just? Examining energy injustices and inequalities in rural Indonesia. Energy Res. Soc. Sci. 71, 101825. https://doi.org/10.1016/j.erss.2020.101825.
Fu, X., Guo, C., & Yang, K. (n.d.). The market-clearing framework of a resilient microgrid with renewable energy considering emission reduction targets. *IET Renewable Power Generation*, *n/a*(n/a). https://doi.org/10.1049/rpg2.12786.
García-García, J., Sarmiento-Ariza, Y., Campos-Rodríguez, L., Rey-López, J., Osma-Pinto, G., 2023. Evaluation of tax incentives on the financial viability of microgrids. Appl. Energy 329, 120293. https://doi.org/10.1016/j.apenergy.2022.120293.
Gasparatos, A., Doll, C.N.H., Esteban, M., Ahmed, A., Olang, T.A., 2017. Renewable energy and biodiversity: Implications for transitioning to a Green Economy. Renew. Sustain. Energy Rev. 70, 161–184. https://doi.org/10.1016/j.rser.2016.08.030.
González, I., Calderón, A.J., Portalo, J.M., 2021. Innovative Multi-Layered Architecture for Heterogeneous Automation and Monitoring Systems: Application Case of a Photovoltaic Smart Microgrid. Article 4. Sustainability 13 (4). https://doi.org/10.3390/su13042234.
Gove, B., Williams, L.J., Beresford, A.E., Roddis, P., Campbell, C., Teuten, E., Langston, R.H.W., Bradbury, R.B., 2016. Reconciling Biodiversity Conservation and Widespread Deployment of Renewable Energy Technologies in the UK. PLOS ONE 11 (5), e0150956. https://doi.org/10.1371/journal.pone.0150956.
Granit, I., 2022. Microgrids through the Energy-Water-Food Security Nexus in La Guajira, Colombia: Increasing water and food security or jeopardizing groundwater levels? Energy Res. Soc. Sci. 93, 102814. https://doi.org/10.1016/j.erss.2022.102814.
Grosse, C., Mark, B., 2023. Does renewable electricity promote Indigenous sovereignty? Reviewing support, barriers, and recommendations for solar and wind energy development on Native lands in the United States. Energy Res. Soc. Sci. 104, 103243. https://doi.org/10.1016/j.erss.2023.103243.
Haghi, E., Raahemifar, K., Fowler, M., 2018. Investigating the effect of renewable energy incentives and hydrogen storage on advantages of stakeholders in a microgrid. Energy Policy 113, 206–222. https://doi.org/10.1016/j.enpol.2017.10.045.
Hakimi, S.M., Hasankhani, A., Shafie-khah, M., Catalão, J.P.S., 2020. Demand response method for smart microgrids considering high renewable energies penetration. Sustain. Energy, Grids Netw. 21, 100325. https://doi.org/10.1016/j.segan.2020.100325.
Hassan, R., Das, B.K., Hasan, M., 2022. Integrated off-grid hybrid renewable energy system optimization based on economic, environmental, and social indicators for sustainable development. Energy 250, 123823. https://doi.org/10.1016/j.energy.2022.123823.
Hau, V.B., Husein, M., Chung, I.-Y., Won, D.-J., Torre, W., Nguyen, T., 2018. Analyzing the Impact of Renewable Energy Incentives and Parameter Uncertainties on Financial Feasibility of a Campus Microgrid. Article 9. Energies 11 (9). https://doi.org/10.3390/en11092446.
He, L., Zhang, S., Chen, Y., Ren, L., Li, J., 2018. The techno-economic potential of a renewable energy-based microgrid system for a sustainable large-scale residential community in Beijing, China. Renew. Sustain. Energy Rev. 93, 631–641. https://doi.org/10.1016/j.rser.2018.05.053.
Henry, C.L., Baker, J.S., Shaw, B.K., Kondash, A.J., Leiva, B., Castellanos, E., Wade, C.M., Lord, B., Van Houtven, G., Redmon, J.H., 2021. How will renewable energy development goals affect energy poverty in Guatemala? Energy Econ. 104, 105665. https://doi.org/10.1016/j.eneco.2021.105665.
Her, C., Sambor, D.J., Whitney, E., Wies, R., 2021. Novel wind resource assessment and demand flexibility analysis for community resilience: A remote microgrid case study. Renew. Energy 179, 1472–1486. https://doi.org/10.1016/j.renene.2021.07.099.
Heydari, A., Garcia, D.A., Keynia, F., Bisegna, F., Santoli, L.D., 2019. Renewable Energies Generation and Carbon Dioxide Emission Forecasting in Microgrids and National Grids using GRNN-GWO Methodology. Energy Procedia 159, 154–159. https://doi.org/10.1016/j.egypro.2018.12.044.
Hirsch, A., Parag, Y., Guerrero, J., 2018. Microgrids: A review of technologies, key drivers, and outstanding issues. Renew. Sustain. Energy Rev. 90, 402–411. https://doi.org/10.1016/j.rser.2018.03.040.
Hirwa, J., Zolan, A., Becker, W., Flamand, T., Newman, A., 2023. Optimizing design and dispatch of a resilient renewable energy microgrid for a South African hospital. Appl. Energy 348, 121438. https://doi.org/10.1016/j.apenergy.2023.121438.
Holdmann, G.P., Wies, R.W., Vandermeer, J.B., 2019. Renewable Energy Integration in Alaska's Remote Islanded Microgrids: Economic Drivers, Technical Strategies, Technological Niche Development, and Policy Implications. Proc. IEEE 107 (9), 1820–1837. https://doi.org/10.1109/JPROC.2019.2932755.
de la Hoz, J., Martín, H., Matas, J., 2023. Editorial on the Special Issue Entitled "Regulatory Frameworks Addressed to Promote Renewable Energy Sources and Microgrids. Regulatory Constraints and Implications on Conception, Design and Energy Management of Microgrids. Article 13. Energies 16 (13). https://doi.org/10.3390/en16135059.
Huang, S., Abedinia, O., 2021. Investigation in economic analysis of microgrids based on renewable energy uncertainty and demand response in the electricity market. Energy 225, 120247. https://doi.org/10.1016/j.energy.2021.120247.
Husein, M., Chung, I.-Y., 2018. Optimal design and financial feasibility of a university campus microgrid considering renewable energy incentives. Appl. Energy 225, 273–289. https://doi.org/10.1016/j.apenergy.2018.05.036.
Iacobucci, R., McLellan, B., Tezuka, T., 2019. Costs and carbon emissions of shared autonomous electric vehicles in a Virtual Power Plant and Microgrid with renewable energy. Energy Procedia 156, 401–405. https://doi.org/10.1016/j.egypro.2018.11.104.
Ibrik, I., 2020. Micro-Grid Solar Photovoltaic Systems for Rural Development and Sustainable Agriculture in Palestine. Article 10. Agronomy 10 (10). https://doi.org/10.3390/agronomy10101474.
Inês, C., Guilherme, P.L., Esther, M.-G., Swantje, G., Stephen, H., Lars, H., 2020. Regulatory challenges and opportunities for collective renewable energy prosumers in the EU. Energy Policy 138, 111212. https://doi.org/10.1016/j.enpol.2019.111212.
Islami, M.S., Urmee, T., Kumara, I.N.S., 2021. Developing a framework to increase solar photovoltaic microgrid penetration in the tropical region: A case study in Indonesia. Sustain. Energy Technol. Assess. 47, 101311. https://doi.org/10.1016/j.seta.2021.101311.
Jaccard, M., Failing, L., Berry, T., 1997. From infrastructure equipment: Community energy management and greenhouse gas emission reduction. Energy Policy 25 (13), 1065–1074. https://doi.org/10.1016/S0301-4215(97)00091-8.
Jalilian, F., Mirzaei, M.A., Zare, K., Mohammadi-Ivatloo, B., Marzband, M., Anvari-Moghaddam, A., 2022. Multi-energy microgrids: An optimal despatch model for water-energy nexus. Sustain. Cities Soc. 77, 103573. https://doi.org/10.1016/j.scs.2021.103573.
Javaid, N., Hafeez, G., Iqbal, S., Alrajeh, N., Alabed, M.S., Guizani, M., 2018. Energy Efficient Integration of Renewable Energy Sources in the Smart Grid for Demand Side Management. IEEE Access 6, 77077–77096. https://doi.org/10.1109/ACCESS.2018.2866461.
Javid, Z., Kejun, L., Ul Hassan, R., Chen, J., 2019. Energy Saving and Carbon Reduction by Utilizing the Renewable Resources and Recycling the Waste of Industries for Power Generation. IEEE 2nd Int. Conf. Autom., Electron. Electr. Eng. (AUTEEE) 2019, 261–264. https://doi.org/10.1109/AUTEEE48671.2019.9033420.
Jha, S.K., Stoa, P., Uhlen, K., 2016. Socio-economic impact of a rural microgrid. 4th Int. Conf. Dev. Renew. Energy Technol. (ICDRET 2016, 1–4. https://doi.org/10.1109/ICDRET.2016.7421518.
Jung, J., Villaran, M., 2017. Optimal planning and design of hybrid renewable energy systems for microgrids. Renew. Sustain. Energy Rev. 75, 180–191. https://doi.org/10.1016/j.rser.2016.10.061.
Kamal, M.M., Mohammad, A., Ashraf, I., Fernandez, E., 2022. Rural electrification using renewable energy resources and its environmental impact assessment. Environ. Sci. Pollut. Res. 29 (57), 86562–86579. https://doi.org/10.1007/s11356-022-22001-3.
Karanasios, K., Parker, P., 2018. Tracking the transition to renewable electricity in remote indigenous communities in Canada. Energy Policy 118, 169–181. https://doi.org/10.1016/j.enpol.2018.03.032.
Karimi, E., Kazerani, M., 2017. Impact of demand response management on improving the social welfare of remote communities through integrating renewable energy resources. IEEE 30th Can. Conf. Electr. Comput. Eng. (CCECE) 2017, 1–6. https://doi.org/10.1109/CCECE.2017.7946739.
Kataray, T., Nitesh, B., Yarram, B., Sinha, S., Cuce, E., Shaik, S., Vigneshwaran, P., Roy, A., 2023. Integration of smart grid with renewable energy sources: Opportunities and challenges – A comprehensive review. Sustain. Energy Technol. Assess. 58, 103363. https://doi.org/10.1016/j.seta.2023.103363.
Keyhani, A., 2016. Design of Smart Power Grid Renewable Energy Systems. John Wiley & Sons.

Kiehbadroudinezhad, M., Merabet, A., Hosseinzadeh-Bandbafha, H., Ghenai, C., 2023. Environmental assessment of optimized renewable energy-based microgrids integrated desalination plant: Considering human health, ecosystem quality, climate change, and resources. Environ. Sci. Pollut. Res. 30 (11), 29888–29908. https://doi.org/10.1007/s11356-022-24051-z.

Kiehbadroudinezhad, M., Merabet, A., Rajabipour, A., Cada, M., Kiehbadroudinezhad, S., Khanali, M., Hosseinzadeh-Bandbafha, H., 2022. Optimization of wind/solar energy microgrid by division algorithm considering human health and environmental impacts for power-water cogeneration. Energy Convers. Manag. 252, 115064. https://doi.org/10.1016/j.enconman.2021.115064.

Kirchhoff, H., Kebir, N., Neumann, K., Heller, P.W., Strunz, K., 2016. Developing mutual success factors and their application to swarm electrification: Microgrids with 100% renewable energies in the Global South and Germany. J. Clean. Prod. 128, 190–200. https://doi.org/10.1016/j.jclepro.2016.03.080.

Klein, S.J.W., Coffey, S., 2016. Building a sustainable energy future, one community at a time. Renew. Sustain. Energy Rev. 60, 867–880. https://doi.org/10.1016/j.rser.2016.01.129.

Kuffar, H., 2020. The Profitability and Affordability of Smart Renewable Microgrid in Sub-Saharan Africa. IEEE Electr. Power Energy Conf. (EPEC) 2020, 1–4. https://doi.org/10.1109/EPEC48502.2020.9320025.

Kumar, N.M., Chopra, S.S., Rajput, P., 2020. Chapter 12—Life cycle assessment and environmental impacts of solar PV systems. In: Gorjian, S., Shukla, A. (Eds.), Photovoltaic Solar Energy Conversion. Academic Press, pp. 391–411. https://doi.org/10.1016/B978-0-12-819610-6.00012-0.

Kumar, N.M., Chopra, S.S., Chand, A.A., Elavarasan, R.M., Shafiullah, G.M., 2020. Hybrid Renewable Energy Microgrid for a Residential Community: A Techno-Economic and Environmental Perspective in the Context of the SDG7. Article 10. Sustainability 12 (10). https://doi.org/10.3390/su12103944.

Kumar, A., Singh, A.R., Deng, Y., He, X., Kumar, P., Bansal, R.C., 2019. Integrated assessment of a sustainable microgrid for a remote village in the hilly region. Energy Convers. Manag. 180, 442–472. https://doi.org/10.1016/j.enconman.2018.10.084.

Lagrange, A., de Simón-Martín, M., González-Martínez, A., Bracco, S., Rosales-Asensio, E., 2020. Sustainable microgrids with energy storage as a means to increase power resilience in critical facilities: An application to a hospital. Int. J. Electr. Power Energy Syst. 119, 105865. https://doi.org/10.1016/j.ijepes.2020.105865.

Lehmann, P., Söderholm, P., 2018. Can Technology-Specific Deployment Policies Be Cost-Effective? The Case of Renewable Energy Support Schemes. Environ. Resour. Econ. 71 (2), 475–505. https://doi.org/10.1007/s10640-017-0169-9.

Lenhart, S., Araújo, K., 2021. Microgrid decision-making by public power utilities in the United States: A critical assessment of adoption and technological profiles. Renew. Sustain. Energy Rev. 139, 110692. https://doi.org/10.1016/j.rser.2020.110692.

Li, M., Zhang, X., Li, G., Jiang, C., 2016. A feasibility study of microgrids for reducing energy use and GHG emissions in an industrial application. Appl. Energy 176, 138–148. https://doi.org/10.1016/j.apenergy.2016.05.070.

Lin, H., Liu, C., Guerrero, J.M., Vasquez, J.C., Dragicevic, T., 2014. Modular power architectures for microgrid clusters. First Int. Conf. Green. Energy ICGE 2014 2014, 199–206. https://doi.org/10.1109/ICGE.2014.6835422.

Luangchosiri, N., Ogawa, T., Okumura, H., Ishihara, K.N., 2021. Success Factors for the Implementation of Community Renewable Energy in Thailand. Article 14. Energies 14 (14). https://doi.org/10.3390/en14144203.

Lund, P.D., Lindgren, J., Mikkola, J., Salpakari, J., 2015. Review of energy system flexibility measures to enable high levels of variable renewable electricity. Renew. Sustain. Energy Rev. 45, 785–807. https://doi.org/10.1016/j.rser.2015.01.057.

Madurai Elavarasan, R., Pugazhendhi, R., Jamal, T., Dyduch, J., Arif, M.T., Manoj Kumar, N., Shafiullah, G., Chopra, S.S., Nadarajah, M., 2021. Envisioning the UN Sustainable Development Goals (SDGs) through the lens of energy sustainability (SDG 7) in the post-COVID-19 world. Appl. Energy 292, 116665. https://doi.org/10.1016/j.apenergy.2021.116665.

Maqbool, U., Tyagi, A., Tyagi, V.V., Kothari, R., 2020. Optimization of the renewable-energy-based micro-grid for rural electrification in the northern region of India. Clean. Technol. Environ. Policy 22 (3), 579–590. https://doi.org/10.1007/s10098-019-01801-1.

Mendes, G., Ioakimidis, C., Ferrão, P., 2011. On the planning and analysis of Integrated Community Energy Systems: A review and survey of available tools. Renew. Sustain. Energy Rev. 15 (9), 4836–4854. https://doi.org/10.1016/j.rser.2011.07.067.

Milis, K., Peremans, H., Van Passel, S., 2018. The impact of policy on microgrid economics: A review. Renew. Sustain. Energy Rev. 81, 3111–3119. https://doi.org/10.1016/j.rser.2017.08.091.

Monagas, M. del C., Corral, S., 2022. Should Western renewable energy microgrids be exported to African islands? Exploring governance, village experiences, and sociotechnical challenges in Cape Verde. Energy Res. Soc. Sci. 93, 102830. https://doi.org/10.1016/j.erss.2022.102830.

Montoya-Duque, L., Arango-Aramburo, S., Arias-Gaviria, J., 2022. Simulating the effect of the Pay-as-you-go scheme for solar energy diffusion in Colombian off-grid regions. ENERGY 244, 123197. https://doi.org/10.1016/j.energy.2022.123197.

Muteri, V., Cellura, M., Curto, D., Franzitta, V., Longo, S., Mistretta, M., Parisi, M.L., 2020. Review on Life Cycle Assessment of Solar Photovoltaic Panels. Article 1. Energies 13 (1). https://doi.org/10.3390/en13010252.

Muttaqee, M., Furqan, M., Boudet, H., 2023. Community response to microgrid development: Case studies from the U.S. Energy Policy 181, 113690. https://doi.org/10.1016/j.enpol.2023.113690.

Naji Alhasnawi, B., Jasim, B.H., Esteban, M.D., 2020. A New Robust Energy Management and Control Strategy for a Hybrid Microgrid System Based on Green Energy. Article 14. Sustainability 12 (14). https://doi.org/10.3390/su12145724.

Nathan, H.S.K., Das, S.D., PS, A.P., 2022. Rural microgrids – 'Tragedy of commons' or 'community collective action. J. Environ. Policy Plan. 24 (4), 391–406. https://doi.org/10.1080/1523908X.2021.2022466.

Nazir, R., Laksono, H.D., Waldi, E.P., Ekaputra, E., Coveria, P., 2014. Renewable Energy Sources Optimization: A Micro-Grid Model Design. Energy Procedia 52, 316–327. https://doi.org/10.1016/j.egypro.2014.07.083.

Neri, A., Butturi, M.A., Lolli, F., Gamberini, R., 2023. Inter-firm exchanges distributed renewable energy generation, and battery energy storage system integration via microgrids for energy symbiosis. J. Clean. Prod. 414, 137529. https://doi.org/10.1016/j.jclepro.2023.137529.

Nfah, E.M., Ngundam, J.M., 2012. Identification of stakeholders for sustainable renewable energy applications in Cameroon. Renew. Sustain. Energy Rev. 16 (7), 4661–4666. https://doi.org/10.1016/j.rser.2012.05.019.

Nwaigwe, K.N., Mutabilwa, P., Dintwa, E., 2019. An overview of solar power (PV systems) integration into electricity grids. Mater. Sci. Energy Technol. 2 (3), 629–633. https://doi.org/10.1016/j.mset.2019.07.002.

Parag, Y., Ainspan, M., 2019. Sustainable microgrids: Economic, environmental and social costs and benefits of microgrid deployment. Energy Sustain. Dev. 52, 72–81. https://doi.org/10.1016/j.esd.2019.07.003.

Parvizimosaed, M., Farmani, F., Anvari-Moghaddam, A., 2013. Optimal energy management of a micro-grid with renewable energy resources and demand response. J. Renew. Sustain. Energy 5 (5), 053148. https://doi.org/10.1063/1.4826880.

Patel, A.M., Singal, S.K., 2019. Optimal component selection of integrated renewable energy system for power generation in stand-alone applications. Energy 175, 481–504. https://doi.org/10.1016/j.energy.2019.03.055.

Peng, J., Lu, L., Yang, H., 2013. Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems. Renew. Sustain. Energy Rev. 19, 255–274. https://doi.org/10.1016/j.rser.2012.11.035.

Perez-DeLaMora, D.A., Quiroz-Ibarra, J.E., Fernandez-Anaya, G., Hernandez-Martinez, E. G., 2021. Roadmap on community-based microgrids deployment: An extensive review. Energy Rep. 7, 2883–2898. https://doi.org/10.1016/j.egyr.2021.05.013.

Peters, J., Sievert, M., Toman, M.A., 2019. Rural electrification through mini-grids: Challenges ahead. ENERGY POLICY 132, 27–31. https://doi.org/10.1016/j.enpol.2019.05.016.

Peters, J., Sievert, M., 2016. Impacts of rural electrification revisited—The African context. J. Dev. EFFECTIVENESS 8 (3), 327–345. https://doi.org/10.1080/19439342.2016.1178320.

Popescu, V.D., Munshaw, R.G., Shackelford, N., Montesino Pouzols, F., Dubman, E., Gibeau, P., Horne, M., Moilanen, A., Palen, W.J., 2020. Quantifying biodiversity trade-offs in the face of widespread renewable and unconventional energy development. Article 1. Sci. Rep. 10 (1). https://doi.org/10.1038/s41598-020-64501-7.

Portalo, J.M., González, I., Calderón, A.J., 2021. Monitoring System for Tracking a PV Generator in an Experimental Smart Microgrid: An Open-Source Solution. Article 15. Sustainability 13 (15). https://doi.org/10.3390/su13158182.

Pradhan, S., Mishra, D., Maharana, M.K., 2017. Energy management system for microgrid pertaining to renewable energy sources: A review. Int. Conf. Innov. Mech. Ind. Appl. (ICIMIA) 2017, 18–23. https://doi.org/10.1109/ICIMIA.2017.7975612.

Qiao, Z., Yang, B., Xu, Q., Xiong, F., Chen, C., Guan, X., Chen, B., 2017. *Energy Trading between microgrids Individual Cost Minimization and Social Welfare Maximization* (arXiv:1702.02748). arXiv. https://doi.org/10.48550/arXiv.1702.02748.

Rezvani, A., Gandomkar, M., Izadbakhsh, M., Ahmadi, A., 2015. Environmental/economic scheduling of a micro-grid with renewable energy resources. J. Clean. Prod. 87, 216–226. https://doi.org/10.1016/j.jclepro.2014.09.088.

Rizvi, S., Abu-Siada, A., 2023. A Review on Active-Power-Sharing Techniques for Microgrids. Article 13. Energies 16 (13). https://doi.org/10.3390/en16135175.

Robert, F.C., Frey, L.M., Sisodia, G.S., 2021. Village development framework through self-help-group entrepreneurship, microcredit, and anchor customers in solar microgrids for cooperative sustainable rural societies. J. Rural Stud. 88, 432–440. https://doi.org/10.1016/j.jrurstud.2021.07.013.

Saeed, M.H., Fangzong, W., Kalwar, B.A., Iqbal, S., 2021. A Review on Microgrids' Challenges & Perspectives. IEEE Access 9, 166502–166517. https://doi.org/10.1109/ACCESS.2021.3135083.

Salkuti, S.R., 2022. Emerging and Advanced Green Energy Technologies for Sustainable and Resilient Future Grid. Article 18. Energies 15 (18). https://doi.org/10.3390/en15186667.

Sarwar, M., Warsi, N.A., Siddiqui, A.S., Kirmani, S., 2022. Optimal selection of renewable energy–based microgrid for sustainable energy supply. Int. J. Energy Res. 46 (5), 5828–5846. https://doi.org/10.1002/er.7525.

Schatz, A., Musilek, P., 2020. Implications of microgrids, economic autonomy and renewable energy systems for remote Indigenous communities. IEEE Electr. Power Energy Conf. (EPEC) 2020, 1–4. https://doi.org/10.1109/EPEC48502.2020.9320073.

Şencan, A. (2012). *Modeling and Optimization of Renewable Energy Systems*. BoD – Books on Demand.

Sheikh, S.R., Sheikh, H., Koreshi, Z.U., 2019. Emerging smart community concept and microgrid technology—A study of lagging skill development in Pakistan. Int. J. Train. Res. 17 (sup1), 170–181. https://doi.org/10.1080/14480220.2019.1639288.

Sherwani, A.F., Usmani, J.A., Varun, 2010. Life cycle assessment of solar PV based electricity generation systems: A review. Renew. Sustain. Energy Rev. 14 (1), 540–544. https://doi.org/10.1016/j.rser.2009.08.003.

Shoeb, M.A., Shafiullah, G.M., 2018. Renewable Energy Integrated Islanded Microgrid for Sustainable Irrigation—A Bangladesh Perspective. Article 5. Energies 11 (5). https://doi.org/10.3390/en11051283.

Singh, M., Balachandra, P., 2019. Microhybrid Electricity System for Energy Access, Livelihoods, and Empowerment. Proc. IEEE 107 (9), 1995–2007. https://doi.org/10.1109/JPROC.2019.2910834.

Smith, C., Burrows, J., Scheier, E., Young, A., Smith, J., Young, T., Gheewala, S.H., 2015. Comparative Life Cycle Assessment of a Thai Island's diesel/PV/wind hybrid microgrid. Renew. Energy 80, 85–100. https://doi.org/10.1016/j.renene.2015.01.003.

Soshinskaya, M., Crijns-Graus, W.H.J., Guerrero, J.M., Vasquez, J.C., 2014. Microgrids: Experiences, barriers and success factors. Renew. Sustain. Energy Rev. 40, 659–672. https://doi.org/10.1016/j.rser.2014.07.198.

Tetteh, S., Yazdani, M.R., Santasalo-Aarnio, A., 2021. Cost-effective Electro-Thermal Energy Storage to balance small-scale renewable energy systems. J. Energy Storage 41, 102829. https://doi.org/10.1016/j.est.2021.102829.

Tooryan, F., HassanzadehFard, H., Collins, E.R., Jin, S., Ramezani, B., 2020. Smart integration of renewable energy resources, electrical, and thermal energy storage in microgrid applications. Energy 212, 118716. https://doi.org/10.1016/j.energy.2020.118716.

Tran, T.T.D., Smith, A.D., 2017. Evaluation of renewable energy technologies and their potential for technical integration and cost-effective use within the U.S. energy sector. Renew. Sustain. Energy Rev. 80, 1372–1388. https://doi.org/10.1016/j.rser.2017.05.228.

Vaahedi, E., Rahimi, F., Amundson, E., 2020. A Versatile Microgrid Management Solution for the Emerging Electricity Grid: Catering to the Full Spectrum of Microgrids. IEEE Electrification Mag. 8 (4), 91–97. https://doi.org/10.1109/MELE.2020.3026495.

Valencia, F., Billi, M., Urquiza, A., 2021. Overcoming energy poverty through micro-grids: An integrated framework for resilient, participatory sociotechnical transitions. Energy Res. Soc. Sci. 75, 102030. https://doi.org/10.1016/j.erss.2021.102030.

Vanadzina, E., Mendes, G., Honkapuro, S., Pinomaa, A., Melkas, H., 2019. Business models for community microgrids. 16th Int. Conf. Eur. Energy Mark. (EEM) 2019, 1–7. https://doi.org/10.1109/EEM.2019.8916368.

Vega Cotto, S., Lee, W.-J., 2017. Microgrid Modular Design for Tribal Healthcare Facilities: Kayenta Health Center PV System Case Study. IEEE Trans. Ind. Appl. 53 (6), 5121–5129. https://doi.org/10.1109/TIA.2017.2725818.

Wade, A., Sinha, P., Drozdiak, K., Mulvaney, D., & Slomka, J. (2018). Ecodesign, Ecolabeling and Green Procurement Policies—Enabling more Sustainable Photovoltaics? *2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC)*, 2600–2605. https://doi.org/10.1109/PVSC.2018.8547210.

Wang, R., Hsu, S.-C., Zheng, S., Chen, J.-H., Li, X.I., 2020. Renewable energy microgrids: Economic evaluation and decision-making for government policies to contribute to affordable and clean energy. Appl. Energy 274, 115287. https://doi.org/10.1016/j.apenergy.2020.115287.

Warneryd, M., Håkansson, M., Karltorp, K., 2020. Unpacking the complexity of community microgrids: A review of institutions' roles for development of microgrids. Renew. Sustain. Energy Rev. 121, 109690. https://doi.org/10.1016/j.rser.2019.109690.

Williams, N.J., Jaramillo, P., Taneja, J., Ustun, T.S., 2015. Enabling private sector investment in microgrid-based rural electrification in developing countries: A review. Renew. Sustain. Energy Rev. 52, 1268–1281. https://doi.org/10.1016/j.rser.2015.07.153.

Wilson, D.G., Robinett, R.D., Goldsmith, S.Y., 2012. Renewable energy microgrid control with energy storage integration. *Automation and Motion*. Int. Symp. . Power Electron. Power Electron., Electr. Drives 158–163. https://doi.org/10.1109/SPEEDAM.2012.6264634.

Wirawan, H., Gultom, Y.M.L., 2021. The effects of renewable energy-based village grid electrification on poverty reduction in remote areas: The case of Indonesia (Elsevier B.V). *Energy Sustain. Dev.* 62, 186–194. https://doi.org/10.1016/j.esd.2021.04.006.

Wolsink, M., 2012. The research agenda on social acceptance of distributed generation in smart grids: Renewable as common pool resources. Renew. Sustain. Energy Rev. 16 (1), 822–835. https://doi.org/10.1016/j.rser.2011.09.006.

Wolsink, M., 2020. Distributed energy systems as common goods: Socio-political acceptance of renewables in intelligent microgrids. Renew. Sustain. Energy Rev. 127, 109841. https://doi.org/10.1016/j.rser.2020.109841.

Worku, M.Y., Hassan, M.A., Abido, M.A., 2019. Real-Time Energy Management and Control of Renewable Energy based Microgrid in Grid Connected and Island Modes. Article 2. Energies 12 (2). https://doi.org/10.3390/en12020276.

Wouters, C., 2015. Towards a regulatory framework for microgrids—The Singapore experience. Sustain. Cities Soc. 15, 22–32. https://doi.org/10.1016/j.scs.2014.10.007.

Wu, Y.J., Liang, X.Y., Huang, T., Lin, Z.W., Li, Z.X., Hossain, M.F., 2021. A hierarchical framework for renewable energy sources consumption promotion among microgrids through two-layer electricity prices. Renew. Sustain. Energy Rev. 145, 111140. https://doi.org/10.1016/j.rser.2021.111140.

Xu, D., Long, Y., 2019. The Impact of Government Subsidy on Renewable Microgrid Investment Considering Double Externalities. Article 11. Sustainability 11 (11). https://doi.org/10.3390/su11113168.

Yadav, P., Davies, P.J., Sarkodie, S.A., 2019. The prospects of decentralized solar energy home systems in rural communities: User experience, determinants, and impact of free solar power on the energy poverty cycle. Energy Strategy Rev. 26, 100424. https://doi.org/10.1016/j.esr.2019.100424.

Yadoo, A., Cruickshank, H., 2012. The role of low carbon electrification technologies in poverty reduction and climate change strategies: A focus on renewable energy mini-grids with case studies in Nepal, Peru, and Kenya. Energy Policy 42, 591–602. https://doi.org/10.1016/j.enpol.2011.12.029.

Zheng, Y., Jenkins, B.M., Kornbluth, K., Træholt, C., 2018. Optimization under uncertainty of a biomass-integrated renewable energy microgrid with energy storage. Renew. Energy 123, 204–217. https://doi.org/10.1016/j.renene.2018.01.120.